National Energy Board

CANADA

Office national de l'énergie

RISK ANALYSIS STUDY

DEVELOPMENT OF A RISK ESTIMATION METHOD

SUSAN JAQUES

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TJ
930
J32

31
Calgary, Alberta
T2P 3H2

311, 6e Avenue s.-o.
Calgary (Alberta)
T2P 3H2

Telephone/Téléphone: (403)292-4800
Facsimile/Télécopieur: (403)292-5503

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1.0 INTRODUCTION

The National Energy Board regulates pipelines that cross provincial and international boundaries. These pipelines carry many different products, such as Natural Gas Liquids (NGLs), crude oil and gas, and sour oil and gas. Implicit in the operation of these pipelines is the possibility of an accidental release of the pipeline contents. If the release occurs upwind from a populated area, and the product released has dangerous properties - for example, NGLs are flammable within certain concentration limits - then there is the possibility of serious harm to the people or environment in the area. In an attempt to quantify this danger, a specific method has been developed, called risk analysis.

Risk analysis has recently become an integral part of the engineering field, particularly regarding construction of new industrial projects. The need to determine the hazards and risks to the public has become a very important part of the planning process. The public is becoming more and more aware of the dangers associated with industrial developments in their communities, and are asking for industrial accountability. In response to this, the industry has begun to address risk management with many of its projects. To illustrate the growing importance of defining project risk, the Canadian Standards Association has just recently developed a Standard for Emergency Planning for Industry (CAN/CSA-Z731-M91), which states that it is mandatory that a risk analysis be performed on a project.

A framework for risk management, from the CSA Risk Analysis Requirements and Guidelines, is shown below:

<---------- RISK MANAGEMENT ---------->

<---------- RISK ASSESSMENT ---------->

<-------- RISK ANALYSIS --------> <---- RISK EVALUATION -----> <--- RISK CONTROL --->

Hazard Identification	-->	Risk Estimation	-->	Risk Acceptance	-->	Option Analysis	-->	Decision Making	-->	Monitoring

The terms above are defined according to CSA:

Hazard - A condition with the potential for causing an undesirable consequence.

Hazard Identification - Recognition that a hazard exists and the definition of its characteristics.

Risk - A measure of probability and severity of an adverse effect to health, property or environment.
Risk is often estimated by the mathematical expectation of the consequence of an adverse event occurring, as a product of probability and consequences. As well, a non-product form of estimation can be presented, such as a 'spectrum of consequences', where each magnitude of consequences has its own corresponding probability of occurrences.

Risk Analysis - The use of available information to estimate risk to individuals, population, property, or the environment. It follows the steps of

Hazard Identification --> Risk Estimation.

Risk Assessment - The process of risk analysis and risk evaluation.

Risk Control - The process of decision-making for managing risk, its implementation, enforcement and re-evaluation of effectiveness from time to time.

Risk Estimation - Determining the extent and probability of adverse effects of the hazard identified, to produce a measure of the level of the health, property, or environmental risks being assessed.

Risk Evaluation - Values and judgements enter decision process explicitly or implicitly, by including consideration of the importance of the assessed risks and associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks, and to consider whether or not the proposed choice as a whole is acceptable.

Risk Management - Complete process of risk assessment and risk control.

This report covers specifically the methods of risk analysis. It can be seen that this is only a small part of the entire risk management spectrum. However, it is also intuitive that if the risk of a project is not known, then the hazards cannot be managed properly.

It is essential that the risk estimation be easily communicated to others. It should be concise and easy to interpret. Risk can be presented in many ways, such as:

- graphs
  i.e., frequency of fatalities vs. number of fatalities
- risk transects
  i.e., frequency of fatalities vs. distance from hazard
- risk contours, which are shown the same way as elevation contours, or
- ranking
  i.e., comparing the risk with common activities.

The most comprehensive way of presenting risk is to rank it with other activities that people participate in regularly. It is easier to understand the implications of the result if it is shown this way. This requires developing a method that will produce a "risk score", which is the probability that a specific result will occur.

This report describes the development of a simple risk analysis calculation that is performed on a spreadsheet (Excel Release 3.0). The spreadsheet is not meant for detailed analyses, but more for comparison or general cases. Also, it was specifically designed to calculate the risks associated with a pipeline carrying NGL products (propane, methane, ethane, etc. and combinations thereof).

2.0 GENERAL RISK ANALYSIS METHOD FOR A PIPELINE RUPTURE

From the CSA Framework for Risk Management, there are two steps to risk analysis:

1. Hazard Identification, and
2. Risk Estimation.

2.1 Hazard Identification

For some industrial activities, the hazards involved with a project are not readily known, and hazard identification becomes an important step in the risk analysis process. Methods such as checklists, statistical approaches or a hazard and operability (HAZOP) study can be performed on hazardous projects such as processing plants or nuclear power plants. However, since this report deals specifically with pipelines, the hazard is already known to be the pipeline failure.

2.2 Risk Estimation

The basic concepts behind risk estimation are probabilities and consequences:

Probability - the likelihood of which an event will occur with specified consequences.

Consequences - the results of a certain event occurring.

Probabilities and consequences are inter-related. Probability is defined as the likelihood of an event occurring with specified consequences. Consequences can be fatalities, property damage or environmental damage. In most risk estimations, consequences are specified as fatalities. The risk estimator must determine the probability that the event will occur, taking into account the specified results. Generally, if the severity of the consequences is high, the probability of occurrence tends to be low. In this report, the hazard is the pipeline rupture, but the event is the rupture *and* the effect it has on the population surrounding the rupture.

2.2.1 Probability

To calculate the probability of a hazard that has already been identified, a technique called 'Event Tree Analysis'(ETA) can be used. There is a simple example of an event tree for an explosion shown in Figure 1. This method is used later in this report to calculate the probability of a pipeline rupture.

Event trees are based on the question "What happens if...?". Each successive event that is determined will result in either a success ("yes") or a failure ("no"). It is difficult to incorporate delayed success or recovery events. However, for a worst-case scenario model, the event tree shows the relationship between the initiating event and the hazardous outcomes of it.

Note that there is an anomaly with the probability part of determining risk. A *probability* can be expressed as 1 in 100 or 1 in a million, which seems to be a unitless number, however, in these cases, it is actually 1 in 100 or 1 million *years*. In risk estimates, the relationship is said to be between probability and consequences, yet the probability looks like it is expressed as a *frequency* in the units of events/year to determine the risk.

Each step in the event tree requires probability or frequency data on the success or failure of the particular event. This data is most likely found in databases of historical incidents of a similar nature. Once all of the probabilities are known, they are simply multiplied together to arrive at a 'frequency of occurence'. Figure 1 shows that the lowest frequency (8.0×10^{-8}) corresponds an event that would result in the most severe consequences: a fire with neither the sprinkler system or fire alarm being activated.

2.2.2 Consequences

Consequences are the result of the hazardous situation caused by the pipeline rupture. Risk assessors deal with adverse consequences such as fatalities, property damage or environmental damage. In this report, the consequences are taken to be fatalities.

When a pipeline ruptures, the gas releases from the pipeline at the point of a rupture. The rate at which it releases will determine the development of the plume. The wind direction and atmospheric stability will determine which area the plume affects. The number of people in the affected area will determine the number of fatalities.

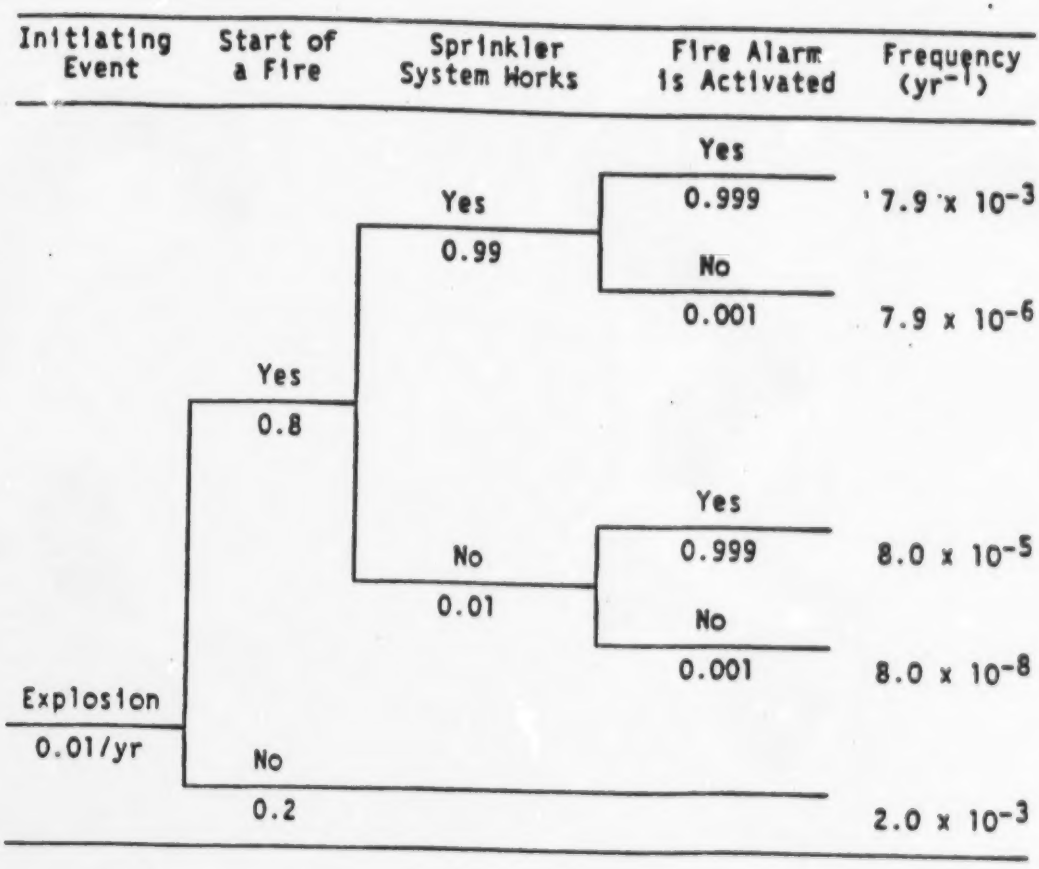


FIGURE 1 - Example of an Event Tree

Consequence calculations are largely done by sophisticated computer models, such as SAFETI (see software summary, Appendix A) by Technica, a British company, and GasCon2, by the Energy Resources Conservation Board (References 11, 12), which is currently being used to determine the safety of sour gas well development in Calgary. Computer models are needed for detailed consequence calculations because of the many factors involved:

- population location
- population density
- size of pipeline rupture,
- type of gas released,
- rate of gas release,
- amount of gas in pipeline section,
- wind direction,
- wind speed,
- ground surface roughness, and
- atmospheric stability.

The ERCB computer program is described in detail in Section 3.2, because it is this method that the Risk Estimation Spreadsheet (RES) was based on.

3.0 RISK ANALYSIS METHOD - EXAMPLES

Quantifying risk can be simple or complicated. The level of complication depends on the availability of appropriate data, and the level of detail that is needed in the analysis. The methods described below illustrate two kinds of risk estimation - assigning of risk factors, and mathematical computations.

3.1 The Lawrence Livermore National Laboratory (LLNL) Method

The LLNL (Lawerence Livermore National Laboratory) Method is a straightforward method that has been developed to calculate risk scores quickly and without specific data pertaining to the project. It incorporates the basic premise that

RISK = CONSEQUENCES x (EXPOSURE x PROBABILITY).

CONSEQUENCES are the undesired result of a sequence of events starting with the initiating event. It is considered in combination with its probability factor, because there are different consequences for every hazard, each with a different probability. Generally, if the consequence seriousness is higher, then the probability of the sequence of events is lower.

(EXPOSURE x PROBABILITY) is a probability term divided into the two subfactors for ease of calculation. EXPOSURE is the probability that the initiating event will occur. The PROBABILITY factor is the probability that the consequences specified will occur given that the

initiating event occurs.

This method has been used in industry. One example is the St. Eustache Mall Expansion project in St. Eustace, Quebec (Reference 19). The mall was intending to expand into a TransNorthern Pipeline's setback area, which caused some concern. The LLNL method was incorporated to help choose the least risky option for maintaining the safety of the area.

The LLNL method is extremely subjective. The user simply assigns whole numbers to each of the three factors above - probability, consequence and exposure - from pre-set tables, shown on the next page, and multiplies the numbers together. The maximum score is 10,000.

The obvious concern with this method is its subjectivity. However, if there is detailed research into the hazard involved, and careful consideration is given to each factor, a reasonable risk score for the use of comparision can be obtained.

3.1.1 LLNL Method Example

Using the scenario at the St. Eustache Mall as an example, the usefulness of the LLNL method will be shown.

There were three basic options available to TransNorthern Pipelines:

1. Install casing around the pipeline, staying within the current servitude;
2. re-route the pipeline around the mall, entirely in the public streets; or
3. re-route the pipeline around the mall, partially in the public streets.

Through a detailed analysis of the different options, by considering every way the pipeline could break and the consequences of each scenario, and by utilizing historical data pertaining to the differences in the options, the committee developing this risk assessment used their engineering judgement to come up with these factors from the tables on the next page for each option:

OPTION	CONSEQUENCES	x	EXPOSURE	x	PROBABILITY	=	TOTAL RISK
1.	15	x	1	x	1	=	15
2.	25	x	3	x	3	=	225
3.	25	x	2	x	3	=	150

With a maximum score of 10,000 for this method, it can be seen that all of these options are relatively safe, and Option 1 is the safest of the choices given.

This method has the advantage of whole numbers to describe the risk, rather than fractional probabilities. However, these whole numbers can mean little to someone who has had no exposure to the LLNL method.

LLNL TABLES OF FACTORS

Table 1 - CONSEQUENCE FACTORS	SCORE
Catastrophe, Numerous Fatalities, Extensive Damage, Major Disruption of Work, Off-Site Health Affected	100
Several Fatalities, Property Damage, Serious Programmatic Interruption	50
Fatality, Property Loss, Work Interruption	25
Permanent Disability, Property Damage No Significant Off-Site Threat	15
Serious Injuries, Property Damage, No Significant Off-Site Threat	5
Minor Injuries, Property Loss, No Work Affected	1

Table 2 - PROBABILITY OF INITIATING EVENT (EXPOSURE)	SCORE
Continuous Threat, Very Likely to Occur, 95% Probability	10
Frequent Threat, 50% Probability	6
Occasional Threat, 1% Probability	3
Unusual Threat, 0.001 Probability	2
Rare Threat, 0.00001 Probability	1
Very Rare Threat, Only Remotely Possible 10^{-7} Probability or Smaller	0.5

Table 3 - PROBABILITY OF COMPLETION	SCORE
Most likely and expected result, 95% Probability	10
Quite Possible, Not Usual, 50% Probability	6
Unusual Sequence of Coincidence, 1% Prob.	3
Remotely Possible Coincidence, 0.001 Prob.	2
Extremely Remote Possibility, 0.00001 Prob.	1
Practically Impossible, 10^{-7} Probability	0.5

3.2 Energy Resources Conservation Board (ERCB) Risk Method

The ERCB undertook a large meteorological/sour gas risk study in the late 80s, and produced an 11 volume set of reports describing their findings. In this project, the ERCB made field observations of plume dispersion, and then applied a computer model to the findings. The ERCB method of finding the mass release rate of the gas after a pipeline rupture is used in the Risk Estimation Spreadsheet.

3.2.1 GasCon2 Program

The GasCon2 Computer Model is a program written in Fortran, and can be purchased through the ERCB. It is applicable only to determining the risks associated with sour gas. It is a very detailed analysis, which requires some detailed input values.

The program calculates gas concentrations and the consequences of release. The model was designed to be used as a tool to estimate a buffer and emergency response planning zones for sour gas facilities. It estimates:

- downwind distance concentration profiles;
- potential hazard zones;
- probability of receiving a lethal concentration dose; and
- potential number of fatalities.

The GasCon2 program assumes that the event has already occurred, and therefore determines only the consequences. The output consists mainly of grids of H_2S concentrations.

The model requires the user to input data for source release rate, source geometry, meteorology, human vulnerability, exposure time, and population density. A complete list of required variables, and the GasCon2 program output, is included in Appendix B.

GasCon2 is divided into 6 separate modules:

1. MASS EMISSION RATE.	Calculates the sour gas release rate for steady state well blowouts.
2. JET EXPANSION MODULE.	Simulates initial behaviour of gas after the release.
3. PLUME RISE MODULE.	Momentum and buoyancy rise, after expansion, including non-vertical or upwind release cases.
4. TRANSIENT RELEASE.	For pipeline models. Finds the pipeline transient mass release rate.
5. PASSIVE DISPERSION.	Calculates ground level plume concentrations as a function of

	distance from release point. Includes factors such as level (ie height) of release, atmospheric stability, and turbulence.
6. FLUCTUATING LOAD AND PROBIT MODULE.	Estimates likelihood of fatalities. 'Toxic load' is a combination of toxic gas concentration and exposure time. The user controls both variables.

Although there are several limitations to the GasCon2 program, which are listed in Appendix B, for sour gas incident consequence prediction GasCon2 is highly suitable. Its output includes a grid of H_2S concentrations over x and y distances. It also supplies a number for maximum potential fatalities. However, this is not a risk result; it is only a value for the consequences. The program may calculate one death per incident, which sounds serious, but if the probability of that incident occuring is 1/1,000,000 years, then the risk of fatality is only one in a million (from the product of probabilities and consequences).

3.2.2 ERCB Risk Approach

Once the consequences are calculated from the GasCon2 program in the units of fatalities per event, then a rigorous event tree analysis is performed on the pipeline in question. This leads to a frequency of hazard in events per year. Then this frequency is multiplied by the consequences to arrive at a societal risk in fatalities per year. As well, an individual risk of fatality is given as a graph of risk vs. downwind distance from the pipeline.

4.0 DEVELOPMENT OF THE RISK ESTIMATION SPREADSHEET (RES)

The purpose of this project was to find an appropriate method of risk analysis to be applied to pipelines carrying hydrocarbons. To do this, literature on existing methods was researched. It was found that most risk analyses were performed with sophisticated computer programs such as the ERCB's GasCon2 Program. For the most part, the literature did not explain specific procedures of calculation.

One of the reasons the RES was developed is because finding an "appropriate method of risk analyis" includes considering such factors as cost and ease of use. The computer model SAFETI developed by Technica (Appendix A) had a 1991 estimated cost of $130,000 for a site license. The ERCB's GasCon2 price is aprroximately $3000 - $5000. As well, as shown in Appendix B, GasCon2 requires data that is very site specific. Moreover, it applies only to sour gas emissions. Therefore, it was decided that purchasing existing software for calculating risk on NGL pipelines was not a feasible option.

The LLNL method was considered because it did not require purchasing a computer software package. However, looking at it closely, one realizes that it is not a simple method. Since it is

up to the user to choose the risk values based on engineering knowledge, it becomes apparent that it is a difficult procedure for a person inexperienced in the pipeline industry. For this reason, a different direction was pursued.

The ERCB GasCon2 method was researched, and because the detailed calculations were given in volume 4 of the 11-volume report produced by ERCB on that project, it was found that some of its theory could be transferred to use with NGL emissions. Confirmation was obtained from the work that F.G. Bercha and Associates had done regarding the Caroline Risk Analysis Project (Reference 2).

4.1 Properties of Hydrocarbons

ERCB's GasCon2 Program was developed specifically for facilities containing sour gas. The method being developed here for the Risk Estimation Spreadsheet was developed for pipelines carrying high vapour pressure (HVP) materials. HVP materials are transported in the liquid state with a vapour pressure in excess of 241 kPa. These materials include ethane, propane, butanes, and ethylene. Natural Gas Liquid (NGL) is commonly transported, which is a mixture of ethane, propane, butane and condensate.

Failure of an HVP pipeline will result in the escape of the liquid hydrocarbon which will flash into a greatly increased volume of vapour at atmospheric pressure. The highly flammable gas is heavier than air, and will flow over the area to lower levels as it disperses. It is only flammable within certain flammability limits; if the concentration is not within these bounds, there is either too much or not enough gas to be ignited.

Each component of NGLs have their own flammability limits. However, NGLs tend to have characteristics between those of propane and butane. The hazards from escaping NGLs are:

- potential explosion from delayed ignition,
- intense heat from the fire,
- oxygen deficiency from the gas cloud displacing air, and
- intense cold from vapour clouds and liquid pools.

An explosion can be caused by any kind of spark within the flammability limits. For example, an explosion in Brenham, Texas in April 1992 is speculated to have been caused by a car starting in a gas-filled ravine. The subsequent pressure wave from the explosion caused damage for a 7 km area, and shook buildings 225 km away. There was one fatality. This report, and the method used in the spreadsheet, is focused on the hazard of potential explosion from delayed ignition of NGL gas plumes.

4.2 Probabilities

From historical data, the frequency or probability of a hazard can be determined. There are other parameters that affect the probability of occurence, as determined by the ERCB report, that were

researched. These parameters include:

- plume ignition — Not all plumes ignite. It was cited by the National Transportation Board (U.S.A.) (Reference 7) that 12% of NGL plumes ignite.

- wind direction — The risk of fatalities is higher if the wind blows the plume towards a populated area. The Atmospheric Environmental Service of Environment Canada produces a series of meteorological data called "Canadian Climate Normals". Volume 5 of this set is the data for wind speeds and directional probabilities for many stations in Canada. It is this source which will provide the wind direction probabilities.

- exposure — This parameter pertains to sour gas emissions. There were estimates as to how often people were outside, because shelter reduces the effects of sour gas toxicity. However, for an NGL explosion, there is little difference in being outside or inside.

- size of rupture — Small pinhole leaks generally do not release enough gas to produce a hazardous situation. It was determined that this factor would be taken into account with the frequency of hazard parameter, in that pinhole leaks would be removed from the historcial data to calculate the frequency.

Using the event tree shown in Figure 1 as an example, a simple event tree specifically for NGL pipeline ruptures was developed (Figure 2). The data for each event is from the example calculation described in Section 6.0. The "exposure" factor incorporates such factors as: the residents being in the area, the Emergency Shut Down Valves being available, and the meteorology being exactly as it is specified.

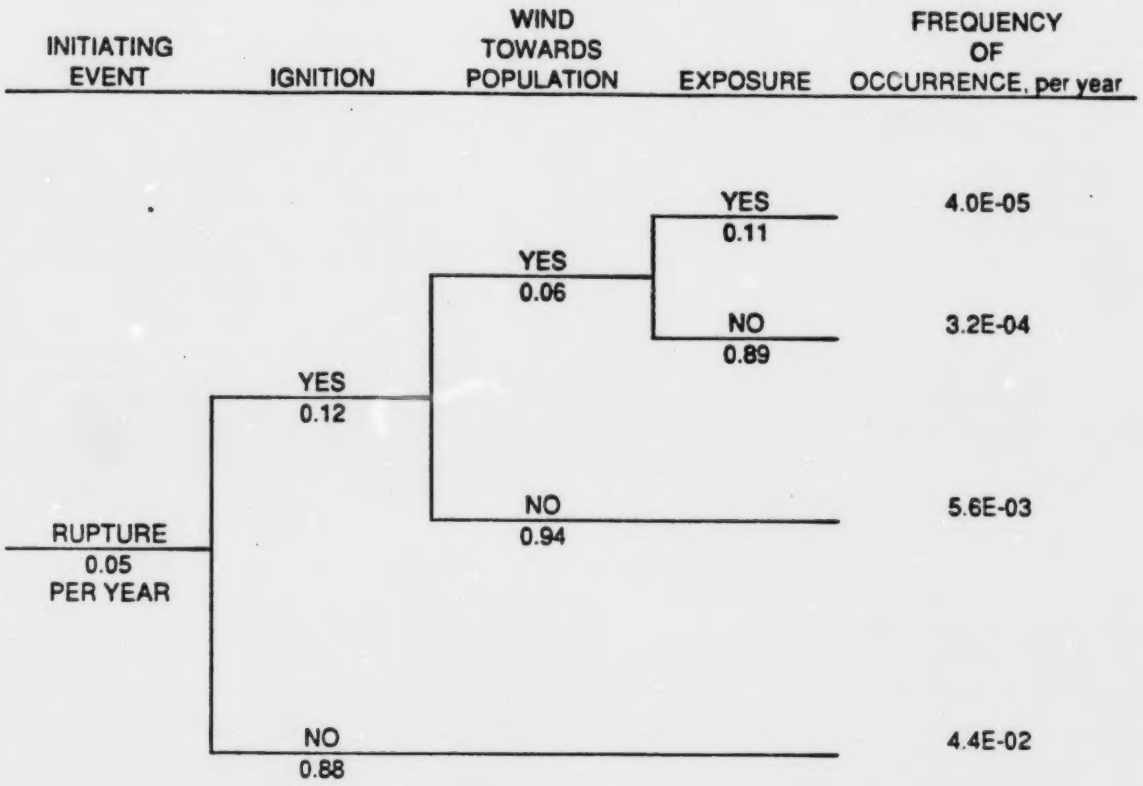
To determine the frequency of the worst-case scenario, calculation of the top branch of the tree is all that is necessary. Therefore, the equation for probability is:

Probability (events/year) = Frequency of Hazard (events/year)
x Probability of Wind Conditions
x Probability of Ignition
x Probability of Exposure.

4.3 Consequences

The consequences required units of fatalities/event so that when multiplied by probability (events/year), a risk value in fatalities/year would be calculated. It was evident that to find the potential number of fatalities, it is necessary to know the area that would be affected by the plume, and the number of people in that area.

FIGURE 2: PIPELINE RUPTURE EVENT TREE



4.3.1 Area Affected

It was determined that to describe any plume development, a mass release rate would be needed (References 17, 18). From the mass release rate, using a method developed by Davies et al (Reference 8), the distances along the centreline of the plume to the flammability limits could be calculated.

The ERCB GasCon2 model provided a basis for the plume dispersion calculations. The calculations are described in ERCB's Report 90B (Reference 11). As described in Section 3.2 of this report, the GasCon2 model uses six different modules to calculate the dispersion characteristics of the plume. For this project, the module for the calculation of a plume release rate was used.

When a pipeline ruptures, the rate of release is a transient one. This means that the emission rate changes with time, as shown in the graph on the next page (Figure 3). At the instant a pipeline ruptures, the release rate is extremely high. As the gas expands and escapes from the confines of the pipeline, the pressure decreases and so does the release rate, until there is no gas left in the pipeline section. It is therefore necessary to apply a transient dispersion model to the pipeline release to calculate a rate of gas released. Then, from wind and atmospheric stability information, a value for the extent of the affected surrounding area can be determined.

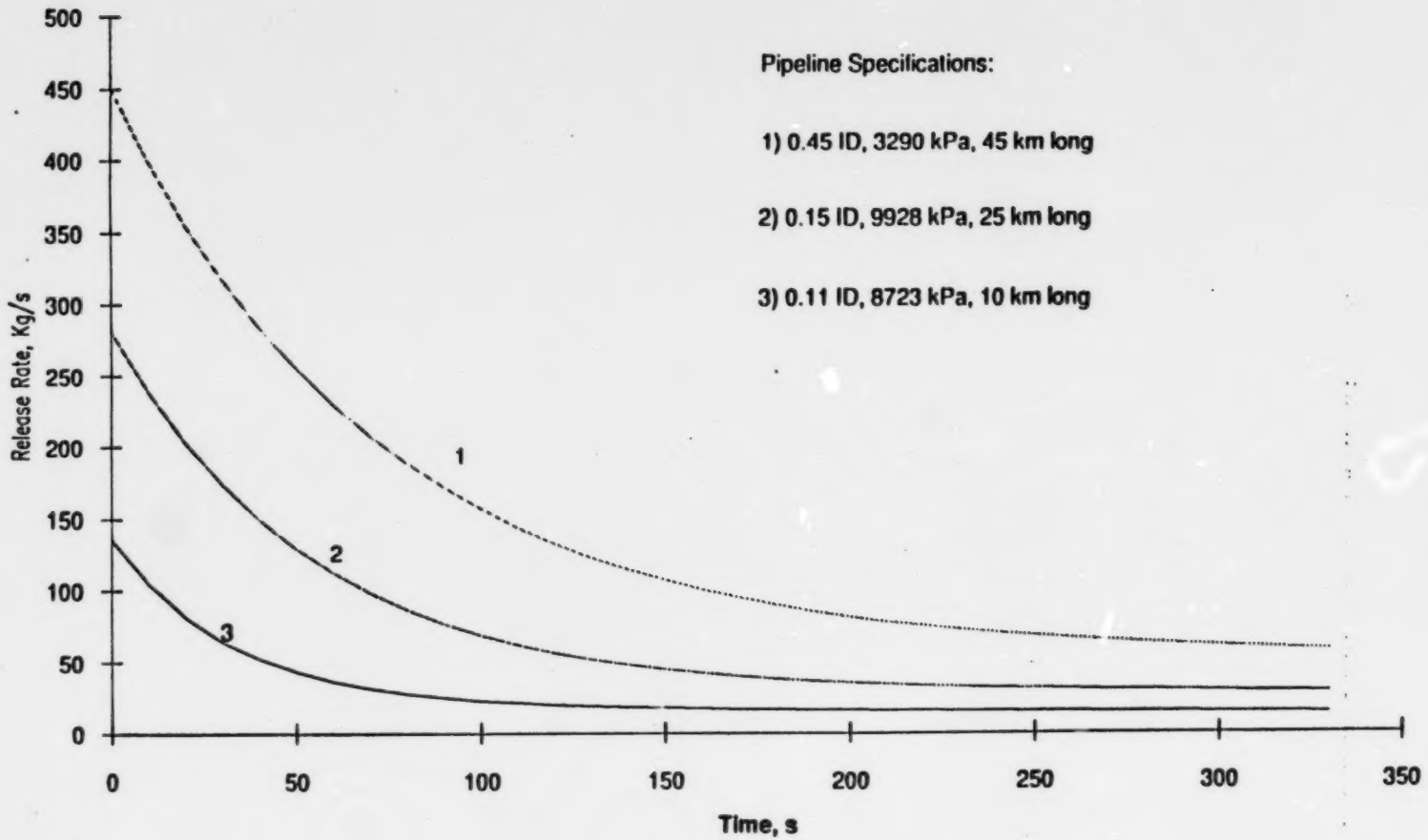
The ERCB double-exponential blowdown model is applied to the pipeline rupture to determine a release rate. This calculation process is described in Section 7.0 . From these calculations, a representative release rate from the duration of 360 seconds of release is calculated.

It should be noted that the Risk Estimation Spreadsheet only calculates the transient release rate for a pipeline. This means that is disregards the jet expansion, plume rise and passive dispersion of the plume. It also simplifies the likelihood of fatalities calculation by taking a fatality rate of 50% per event, disregarding human response to the event. This means that the consequence calculations in the present model could be over-pessimistic.

The GasCon2 model calculates hazard zones for a user-given H2S concentration. However, for this project, it was necessary to account for the explosion potential of hydrocarbons. Hydrocarbons are flammable, but only within certain concentration limits. Therefore, the spreadsheet had to be capable of calculating the overpressure circles from an NGL explosion. It is the overpressure waves from the NGL explosion that can cause fatalities and substantial damage (Reference 1). The explosion hazard radius is dependent on the TNT (Tri Nitro Toluene, an explosive) equivalent weight of fuel in the vapour cloud. From Bercha's calculations of overpressure circle diameter versus TNT equivalent (Figure 4), a relationship between the two was estimated (see section 7.2).

With the diameter of the overpressure circle known, an affected area can be easily calculated.

FIGURE 3 - Pipeline Rupture with a Transient Release



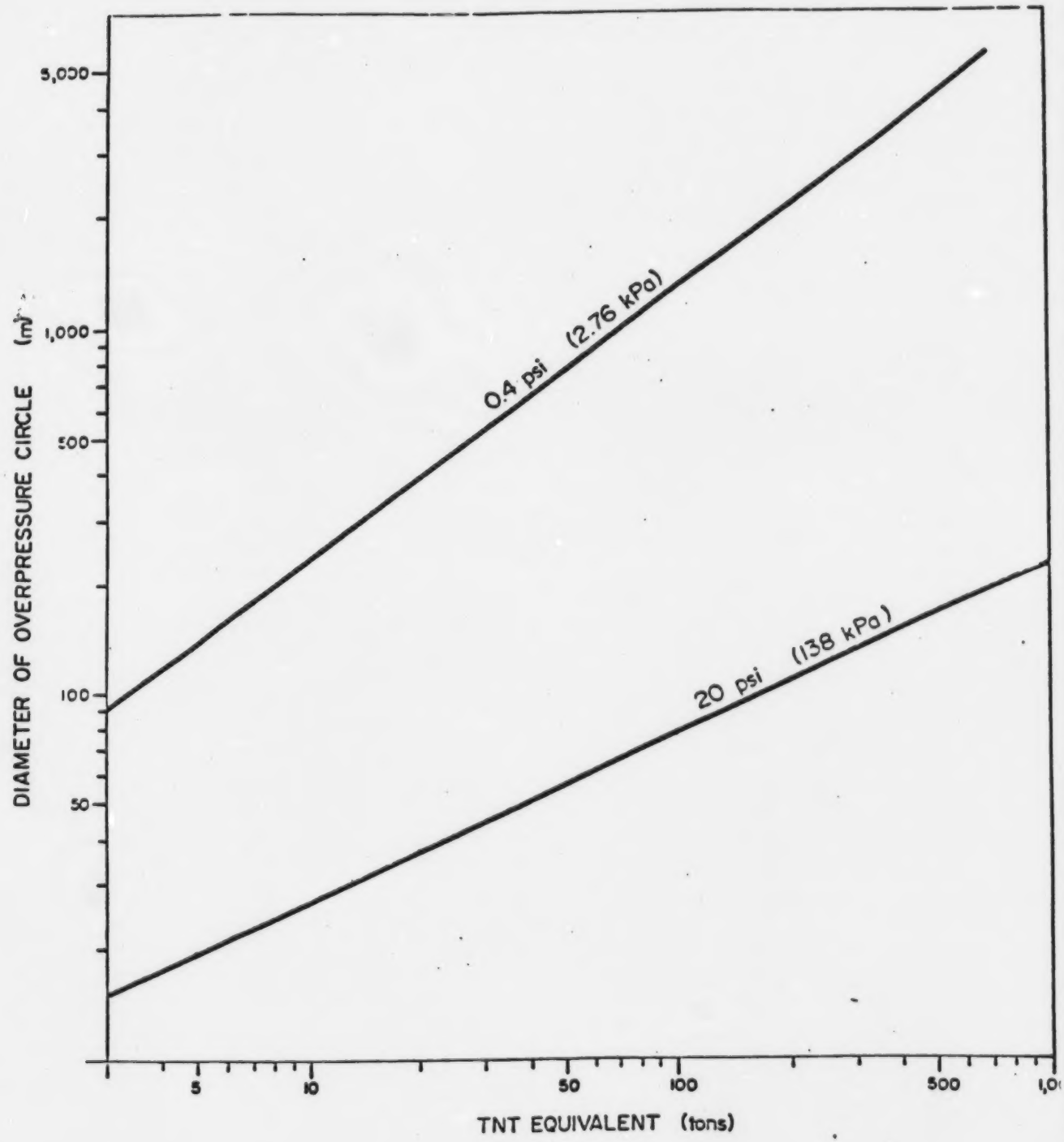


FIGURE 4 - DIAMETER OF OVERPRESSURE CIRCLES VS. EXPLOSIVE YIELDS OF TNT EQUIVALENT

- FROM BERCHA (1983) AND BRASIE (1976) -

4.3.2 Population

The Canadian Standards Associated requires different design factors for pipelines depending on the population of the immediate area. In section 5.3 of CAN/CSA-Z184-M86 (Gas Pipeline Systems), the class locations are described in terms of "dwelling units intended for human occupancy" as:

Class Location 1 - Contains 10 or fewer dwelling units
Class Location 2 - Contains 10-46 dwelling units
Class Location 3 - Contains more than 46 dwelling units.

In the Standard, these class location assignments apply to areas that extend 200 m on both sides of the centreline of any continuous 1.6 km length of pipeline. This calculates to a rectangular area of 64 ha. Since it is assumed that most analyses performed with this spreadsheet will be for pipeline sections that run through less populated areas, the class 4 designation for buildings that are more than 4 storeys high has been omitted. These situations can be assumed to fall under the Class Location 3 designation.

It is required by the National Energy Board that pipeline companies designate Class Locations for the lengths of their pipelines. From this information, it is possible to obtain the approximate number of dwelling units in the area being studied. It has been estimated that on average there are 3 people/dwelling unit, so a population density can be calculated.

4.3.3 Combining Area and Population

With both the area known that is affected by the plume and the estimated population of that area, by multiplying the two together a maximum potential fatalities value can be calculated. A fatality rate of 50% is multiplied in as well in the spreadsheet, because 50% fatalities is considered catastrophic.

4.4 Limitations of the Risk Estimation Spreadsheet

This method of calculating risk is only a simple representation of a very complex subject, and there were many assumptions made during its development.

Since the Risk Estimation Spreadsheet (RES) is modelled after GasCon2, some of the 11 limitations listed in Appendix B apply to the RES as well. Following is a list of limitations and assumptions regarding the RES:

1. The release rate from a pipeline after a rupture is transient, with a very high release rate at t=0, and a gradual decrease in the rate of change. The spreadsheet calculates a representative release rate by calculating the change in release rate over 10 second

intervals, and when that change is less than 1 kg/s, it is assumed to have reached steady state, and an average release rate is taken up to that point.

2. The values for vertical and horizontal dispersion (θ and ϕ) are broad estimates, unless a specific atmospheric stability class and surface roughness are provided. For a general case, the average values are used.

3. This model is only applicable to low wind situations. The model is based on an equation that divides by the wind speed to calculate the distances to the flammability limits, therefore a no-wind scenario is impossible, and a high wind situation will render the equation ineffective (Davies et al, 1991).

4. Only end pipe ruptures are evaluated.

5. The RES cannot evaluate horizontal cross wind releases.

6. The RES assumes constant atmospheric conditions throughout the event.

7. Flat and homogenous terrain conditions are assumed. Large hills and valleys create steering or deflecting effects that are not accounted for. Moderately rough terrain can be modelled by using an appropriate surface roughness value.

8. The RES includes a probability factor to account for the possibility of people being away from their residence, or reacting to a warning. It is a collaboration of data from various sources, and has little scientific backing.

5.0 RISK ESTIMATION SPREADSHEET EXAMPLE

This section describes each spreadsheet input value separately.

PIPELINE COMPANY — For the User's own information and records.

PIPELINE DATA

Inner Diameter (ID) — Sometimes only the outer diameter (OD) is given in the company facility summaries. Past incident reports sometimes give wall thicknesses. The user must calculate the inner diameter:
ID = OD - Wall Thickness.

Segment Length — Preferably, determine the length between Emergency Shut Down Valves, if that information is available. The program takes into account the time to react to the rupture by

	multiplying the length by 1.3 for an extra amount of gas in segment.
Rupture Fraction	The decimal value of the cross-sectional area of the rupture divided by the cross-sectional area of the pipeline.
Friction Factor	Generally 0.014 for pipelines. It can be altered if specific factor is known.
GAS DATA	
Type of Gas in Pipeline	For the user's information. For NGLs, assume propane characteristics.
Pressure	Operating or Maximum Operating Pressure, in KPa, whichever is available.
Molecular Weight	NGL can be assumed to have the characteristics of propane. The molecular weight tends to make a difference in diffusion capabilities, so if NGL component percentages are known, the corresponding molecular weight can be calculated from the tables provided in the user's guide (Appendix D) which give molecular weights for a number of hydrocarbons.
Upper/Lower Flammability Limits	These are given in the user's guide tables. As stated above, NGL generally has the characteristics of propane. The gas will not ignite unless it is within this range of concentration in the air.
Gas Temperature	Generally, NGLs flow in pipelines at ambient temperatures, about 10°C, or 283 K.
Specific Heat Ratio	Given as 1.26 for Natural Gas (Reference 20).
POPULATION DATA	
Approximate Location	For user's reference. Use nearby cities or towns, because wind probabilities are given by city.
Direction to Population	This is to aid in determining a wind probability. If the direction to the population is known, then the appropriate wind can be selected. If the population is to the west of the pipeline, then an east wind would cause the most concern. This is an optional input.

Class Location	The Canadian Standards Association requires different designs depending on the population in the area. The Class Locations are as described in Section 5.2.2. The spreadsheet assumes averages of 5, 30 and 60 dwelling units respectively if Class 1, 2, or 3 is entered.
Actual Dwelling Units/ha	If the company supplies the exact information of the number of dwelling units, there is a place to include it. The user must convert the data to d.u./ha. If the exact number is not known, a zero is the default, and the program uses the average from the Class given above. Alternatively, a table with approximate dwelling unit densities is given in the tables section of the user's guide. These numbers can also be used as estimates when no population information is known.
Mortality Rate	Selected as 0.5, or 50% fatalities. This is considered a catastrophic situation, and this program models worst-case scenarios. The mortality rate can be adjusted.

METEOROLOGICAL DATA

Wind Speed	Generally, use 4 m/s. Alternatively, the user can obtain a most probable wind speed or a directional wind speed appropriate to the population from the wind tables in the guide. The program cannot calculate 0 m/s winds, nor is it applicable to high wind situations (> 6 m/s).
Theta (θ) (Horiz. Dispersion) Phi (ϕ) (Vertical Dispersion)	These values are found in Table 3 in the User's Guide (Appendix D). They were derived from the standard deviation of crosswind and vertical wind components, divided by the mean wind speed. They are grouped according to atmospheric stability classes and ground surface roughness. Generally, classes correspond as follows: Unstable atmosphere (daytime) - A, B, C Neutral (dawn and dusk) - D Stable (night) - E, F These factors are most applicable to low wind speed conditions (1 - 5 m/s).

PROBABILITY DATA

Frequency of Hazard	This is obtained from historical data on the pipeline's incidents. The NEB's incident database summarizes all incidents for pipelines under NEB's jurisdiciton. If possible, data should be analysed and events should be removed if they are not applicable to the scenario being developed. For example, if a 100% rupture is being modelled, small leaks should not be included in the frequency of occurrence data. From Reference 20, major ruptures are cited to occur at a freqency of about 7.5×10^{-6} per km-year.
Probability of Wind Conditions	If the population is located to the east of the pipeline, then the probability of a west wind (ie, blowing from the west to the east) should be found. The tables included in the user's guide are from the Atmospheric Environmental Service, and are by no means comprehensive. The full wind data book (Reference 19) is available at the ERCB library.
Probability of Ignition	This factor takes into account that not all plumes ignite. This value can be altered if a different ignition probability is known.
Probability of Exposure	This accounts for the fact that people are not always in their house, and on the other hand, the fact that if they are in their house, and they are in the overpressure hazard circle, there is the possibility of building damage which would be a threat to the people in the house. This factor can be adjusted according to the location and type of people in the area (ie, farmers, townspeople).

5.1 Spreadsheet Example Data

Using the Petroleum Transmission Company data, a risk analysis is followed through with calculations visible. This shows the steps that the computer follows as it calculates a pipeline risk.

The information needed for the estimation is as follows:

PIPELINE COMPANY		**PTC**
PIPELINE DATA		
Inner Diameter (m)	(d)	0.1589 m
Pipeline Length (km)	(L)	25 km
Rupture Fraction	(RF)	1.0
Friction Factor	(F)	0.014
GAS DATA		
Type of Gas in Pipeline		NGL (use propane characteristics)
Pressure (Pa)	(P)	9928 KPa
Molecular Weight of Gas	(mw)	44 g/mol
Upper Flammability Limit	(C_u)	910 ppm
Lower Flammability Limit	(C_l)	210 ppm
Gas Temperature	(T)	283 K
Specific Heat Ratio	(k_c)	1.26
POPULATION DATA		
Approximate Location		Medicine Hat, AB
Class Type		1
Actual Dwelling Units		0
Mortality Rate		0.5 fatalities/event
METEOROLOGICAL DATA		
Wind Speed	(U)	4 m/s
Theta (horiz. dispersion)	(θ)	10 degrees
Phi (vertical dispersion)	(ϕ)	5 degrees
PROBABILITY DATA		
Frequency of Hazard		2.0E-03
Probability of Wind		0.047
Probability of Ignition		0.12 (Reference 7)
Probability of Exposure		0.11 (selected)

5.2 Spreadsheet Example Calculations

This section describes in detail the calculations that the Risk Estimation Spreadsheet would performed on the example data described above. The spreadsheet printout is included in the User's Guide (Appendix D). The purpose of all of the steps leading to the risk score is to find the area affected by the plume. To find this area, one needs to find the distances along the plume centerline to the upper and lower flammability limits. To find these distances, a mass release rate is required so the plume behaviour can be modelled. The mass release rate is calculated using the ERCB Transient Release Module from the GasCon2 Program. Then this mass release rate is used in an equation by Davies et al, which incorporates atmospheric influences, to calculate distances (step 11). The epicenter of the potential explosion is assumed to be midway between these distances. An overpressure circle diameter is calculated through TNT explosion equivalency, and with this, a hazard area is calculated (see Figure 5).

The distance to X_1 and X_2 will depend on the mass release rate. The equation for a double exponential model for the blowdown of a pressurized pipeline (Reference 11) is:

$$m_e = \left[\frac{\Gamma m_o}{1+\eta}\right] e^{-\frac{t}{\eta^2 \varepsilon}} + \eta e^{-\frac{t}{\varepsilon}}$$

m_e = event release rate, kg/s
Γ = inertial delay factor = 0.5 from experimental data (ERCB, 1990)
m_o = initial gas release rate (kg/s) at time t = 0 (step 5)
t = time after release (s)
η = mass conservation factor (step 8)
$= M_t/\varepsilon\Gamma m_o$
M_t = total mass to be released (kg) (step 7)
ε = time constant (step 6)

To calculate the various unknowns in the above equation, several steps are needed. Following are the steps that the spreadsheet goes through to arrive at a mass release rate for the Petroleum Transmission Company's pipeline carrying NGLs, which have the same characteristics as propane.

1. Gas Constant R

The gas constant is needed to find the speed of sound in the gas.

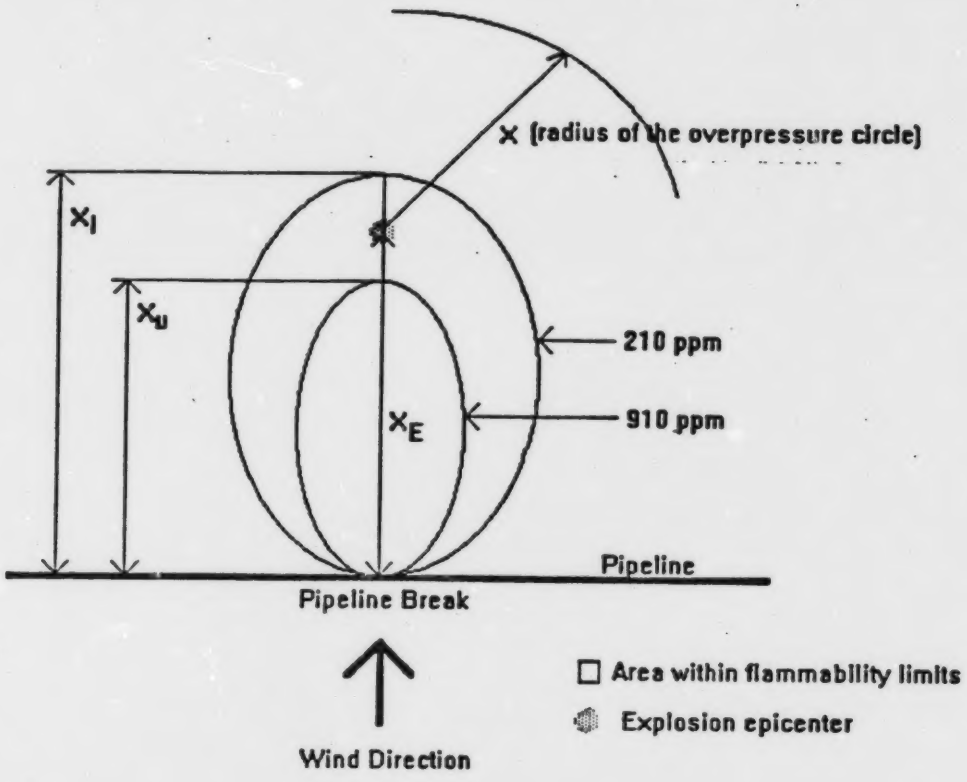


Figure 5: PLAN VIEW OF A PIPELINE RUPTURE

$$R_e = \frac{R}{mw} = \frac{8.314 J/mol \cdot K}{44\ kg/kmol} = \frac{8.314 \times 1000 J/K}{44\ kg} = 189 \frac{J}{kg \cdot K}$$

R = Universal Gas Constant
mw= gas molecular weight

Gas Constant R_e = 189 J/KgK

2. Speed of Sound C in the NGL

The sonic velocity in the NGL is needed for the calculation of a time constant (step #6).

$$C_o = \sqrt{k_e R_e T} = \sqrt{(1.26)(189)(283)} = 259.6$$

k_e = ratio of specific heats for NGL
T = temperature of gas in pipeline (K)

Speed of Sound C = 260 m/s

3. Pipeline Cross Sectional Area A_p

The pipeline cross-sectional area is used to calculate the total mass in the pipeline segment, as well as the rupture area.

$$A_p = \pi \frac{d^2}{4} = \pi \frac{(0.1589)^2}{4} = 0.02$$

d = diameter of the pipeline, m

Pipeline Cross Sectional Area A_p = 0.02 m^2

4. Area of the Rupture A_r

$$A_r = A_p \times \text{Rupture Fraction} = 0.02 \times 1.0 = 0.02\ m^2$$

Area of the Rupture A_r = 0.02 m^2

5. Initial Mass Release Rate m_o

$$m_o = \frac{PA_r\sqrt{K_o}}{\sqrt{R_o T}} \left(\frac{2}{k_o+1}\right)^{\frac{1}{2}\frac{k_o+1}{k_o-1}}$$

P = Pressure in pipeline, Pa
and other variables are as defined previously.

$$m_o = \frac{(9928K)\,(0.02)\sqrt{1.26}}{\sqrt{(189)\,(283)}} \left(\frac{2}{(1.26)+1}\right)^{\frac{1}{2}\left(\frac{2.26}{0.26}\right)} = 562$$

$P = 9928K = 9928 \times 10^3$ Pa

Initial Mass Release Rate m_o = 562 kg/s

From the ERCB's explanation of these equations, it is stated that the initial mass rate equation in the above step is based on adiabatic choked flow theory. At the onset of a pipeline rupture, an expansion wave travels down the pipeline at the local speed of sound. At the rupture exit, the gas flow behind the wave accelerates to sonic velocity. Typically, the region of significant gas acclereation is confined to a length of pipeline approximately 200 diameters upstream of the rupture point. This region of the flow is assumed to be determined by an adiabatic process in which the sum of the internal and kinetic energies of the flow remains constant.

Beyond approximately 200 diameters upstream of the ruptre point, the gas flow is characterized by a relatively small change in gas velocity. This, coupled with the fact that many pipelins are buried in the ground which acts as a thermal reservoir, indicates that much of the pipeline gas during the entire blowdown time is undergoing an isothermal process. For most of the blowdown time and for almost all the pipeline segment length, the pipeline is releasing gas as a fixed volume, isothermal (decreasing pressure) containment vessel. The expression for the time constant ε (step 6) is based on isothermal flow theory.

6. Time Constant ε

This constant accounts for the hole size related to the pipeline cross-sectional size

(Reference 11). It is used to find the mass constant η.

$$\varepsilon = \frac{2}{3}\frac{L}{C}\frac{d}{k_o FL}(rf)^3\left(\frac{k_o+1}{2}\right)^{\left(\frac{3}{2}\frac{k_o+1}{k_o-1}\right)}\left[\left(1+\left(\frac{k_o+1}{2}\right)^{-\frac{k_o+1}{k_o-1}}(rf)^2\frac{k_o FL}{d}\right)^{\frac{3}{2}}-1\right]$$

L = pipeline segment length, m
F = pipeline friction factor
rf = rupture fraction (Rupture Area/Pipeline Area)

and other variables are as previously defined.

$$\varepsilon = \left[\frac{2}{3}\frac{25K}{213}\frac{0.1589}{(1.26)(0.014)(25K)}(1.0)^3\left(\frac{2.26}{2}\right)^{\frac{3}{2}\frac{2.26}{0.26}}\right] \quad x$$

$$\left[\left(1+\left(\frac{2.26}{2}\right)^{-\frac{2.26}{0.26}}(1.0)^2\frac{(1.26)(0.014)(25K)}{0.1589}\right)^{\frac{3}{2}}-1\right]$$

L = 25K = 25 000 m

Time Constant ε = 3388 s

7. Total Mass M, of NGL Available

The total mass available is needed to calculate the mass conservation factor.

$$M_t = \frac{(1.3L)A_p P}{R_o Z T} = \frac{(1.3)(25K)(0.02)(9928K)}{(189)(1.0)(283)} = 119657$$

The 1.3(L) takes into account the gas that comes into the pipe segment in the time it takes to close the Emergency Shut Down Valves.

Total Mass M_t = 119657 kg

8. Mass Conservation Factor η

This constant ensures that the total mass to be released will be recovered upon integration

8. Mass Conservation Factor η

This constant ensures that the total mass to be released will be recovered upon integration of $m_e(t)$ dt.

$$\eta = \frac{M_t}{\Gamma t m_o} = \frac{119657}{(0.5)(3388)(562)} = 0.13$$

Note that the values in the Mass Constant equation were all calculated in previous steps.

Mass Conservation Factor η = 0.13

9. Event Mass Release Rate M_e

A double exponential model for the blowdown of a pressurized pipeline (ERCB,1990).

$$m_e = \left[\frac{\Gamma m_o}{1+\eta}\right] x \left[e^{-\frac{t}{\eta^2 s}} + \eta e^{-\frac{t}{s}}\right]$$

$$m_e = \left[\frac{(0.5)(562)}{1+(0.13)}\right] x \left[e^{-t/[0.13^2(3388)]} + (0.13)\, e^{-t/3388}\right]$$

This equation is evaluated for time t = 0 to 360 s.
The spreadsheet calculates the difference in release rate over each 10 second interval, and then averages those release rates over the time in which the change in release rate is greater than 1 kg/s. These calculations are shown on the next page.

Event Mass Release Rate M_e = 109 kg/s (representative of m_e over time)

10. Convert Mass Release to a Volume Release Q

From the ideal gas law, PV = mR_eT, and

$$Q = \frac{M_e R_e T}{P} = \frac{(109)(189)(283)}{(9928x10^3)} = 0.6$$

Volume release rate Q = 0.411 m^3/s

Mass Release Rate
(the 'change' at Time t=0 is 10000 so the initial release rate is included in averaging - the criteria states a change greater that 1.0 kg/s, but there is no change at time t=0 so a dummy value is included.)

Time, s	Release, kg/s	Change, kg/s
0	561.86	10000
10	238.33	323.53
20	202.97	35.36
30	173.62	29.35
40	149.25	24.37
50	129.02	20.23
60	112.22	16.80
70	98.26	13.95
80	86.67	11.59
90	77.03	9.63
100	69.03	8.01
110	62.37	6.66
120	56.83	5.54
130	52.22	4.61
140	48.38	3.84
150	45.18	3.20
160	42.51	2.67
170	40.28	2.23
180	38.41	1.87
190	36.85	1.56
200	35.54	1.31
210	34.43	1.10
220	33.50	0.93
230	32.72	0.79
240	32.05	0.67
250	31.49	0.57
260	31.00	0.48
270	30.58	0.42
280	30.22	0.36
290	29.91	0.31
300	29.64	0.27
310	29.40	0.24
320	29.18	0.21
330	28.99	0.19
340	28.82	0.17
350	28.66	0.16
360	28.51	0.15

Database Criteria		
Time, s	Release, kg/s	Change, kg/s
		>1.0

Average Release Rate = 109 kg/s

11. Distances to Lower and Upper Flammability Limits X_l, X_u

Using an equation from Davies et al (1991), the distances along the plume centerline from the source to the upper and lower flammability limits can be found.

$$X_{u,l}^2 = \frac{1}{\theta\phi U}\frac{Qx10^6}{2\pi C_{u,l}}\left(\frac{180}{\pi}\right)^2$$

U = wind speed, m/s
X_l = distance to lower flammability limit, m
X_u = distance to upper flammability limit, m
θ = horizontal dispersion factor, degrees
ϕ = vertical dispersion factor, degrees
C_l = lower flammability limit, ppm
C_u = upper flammability limit, ppm

θ (Theta) and ϕ (Phi) are related to the atmospheric stability and the surface roughness of the ground in the area. Table 3 in the User's Guide (Appendix E) shows this relationship.

Stability Class:

There wasn't enough data obtained regarding the frequency of the specific stability classes (A-F) for each major center in Canada to help choose which class to use. Judgement and sensitivity tests should be performed regarding the stability classes. On Table 3 in the User's Guide, each class has a name for the atmospheric conditions: unstable, stable or neutral. Basically, *unstable* atmospheric conditions occur during the daytime when there is surface heating from the sun and the air is rising through the atmosphere. A *stable* atmosphere occurs at nighttime when there is no heat reflection from the earth. *Neutral* conditions generally occur at dawn and dusk, during the transition period between the other classes. It is impossible to predict when a pipeline will rupture, and therefore very difficult to determine a stability class to assign.

Surface Roughness:

The only information available regarding surface roughness values was:

15 cm high crop stubble:	Zo = 1 cm
snow cover:	Zo = 0.2 cm
1 m high crop:	Zo = 5 cm.

It is from this information that Zo values for choosing θ and ϕ must be deduced. The data in Table 3 is averaged over the 4 surface roughness values, however there are still 6 stability classes to choose from. For this example, the values are arbitrarily chosen as θ=10 and ϕ=5.

$$X_u^2 = \frac{1}{(10^\circ)(5^\circ)(4)} \frac{0.6x10^6}{2\pi(210ppm)} \left(\frac{180}{\pi}\right)^2$$
$$X_l^2 = \frac{1}{(10^\circ)(5^\circ)(4)} \frac{0.6x10^6}{2\pi(910ppm)} \left(\frac{180}{\pi}\right)^2$$

$X_u = 41$ m
$X_l = 84$ m (Lower flammability concentration will be further from the source.)

12. Distance to Explosion Epicenter X_E

The explosion epicenter is assumed to be midway between X_u and X_l. See Figure 5.

$$X_E = \frac{X_u + X_l}{2} = \frac{41+85}{2} = 63$$

Distance to Explosion Epicenter $X_E = 63$ m

13. NGL Mass Within Flammability Limits M

Using the method by Bercha (Reference 1), the mass within the flammability limits can be calculated:

$$M = \frac{M_e(X_l - X_u)}{U} \times 60\% = \frac{109kg/s(44m)}{4m/s} x60\% = 723kg$$

The 60% takes into account the shape of the plume, and that the width of the distance between the flammability limits is not $(X_l - X_u)$ throughout (see Figure 5).

Mass Within Flammability Limits M = 245 kg

14. TNT Equivalent of Explosion

It is estimated (Reference 1) that only 20% of the heat of combustion from an explosion is translated into overpressure energy. The TNT equivalent is taken to be:

total mass / 20 % of the heat of combustion (Bercha, 1987).

For most NGLs, the Heat of Combustion = 509.86 kJ/kg (GPSA).

TNT Equivalent = 723/(0.2)509.86 = 7 tons

TNT Equivalent = 7 tons

15. Radius of Overpressure Circle X

Exposure to a 138 kPa overpressure is expected to result in 50% mortalities (Reference 1). From Bercha and Brasie, an equation was developed by curve-fitting for relating overpressures to a radius around the epicenter (Figure 4):

$$LOG(2X) = 0.453\ LOG(Y) + 0.981$$

Where: X = Distance from epicenter to 138 kPa boundary, m
Y = TNT equivalent of explosion (tons).

$$LOG(2X) = 0.453\ LOG(7) + 0.981$$

$$X = 12 \text{ m}$$

16. Radius r of Hazardous Area

The radius of the hazardous area =

radius of overpressure circle + distance from epicenter to rupture

$$r = X + X_E$$
$$r = 12 + 63 = 75 \text{ m}$$

Radius r = 75 m

17. Calculation of Hazardous Area A

$$A = \pi r^2 = \pi(75)^2 = 8786 \text{ m}^2$$

Hazardous Area A = 8786 m^2

With an affected area calculated, it is now necessary to determine the population of that area.

18. Dwelling Units by Class Location Specification

CSA specifies different design factors depending on the population density of the surrounding area. These specifications can be seen in CAN/CSA-Z184-M92. The spreadsheet uses an average number of dwelling units in each Class Location.

The Spreadsheet uses an IF-THEN logical statement to determine the number of dwelling units (d.u.):

IF Class Location = 1, THEN # dwelling units = 5
IF Class Location = 2, THEN # dwelling units = 30
IF Class Location = 3, THEN # dwelling units = 60.

Dwelling Units d.u. = 5

19. Population Density (P.D.) by Class Specification

P.D. = (d.u. x 3 persons/d.u.) / 64 ha.

The 64 ha is the size of the CSA specified segment to classify population zones by.

Population Density P.D. = 0.23 persons/ha

20. Population Density by User Input

If the user specifies a particular dwelling unit density, in d.u./ha, then the spreadsheet uses that value to calculate a population density:

P.D. = d.u. x 3 persons/d.u.

21. Population Density

Generally, if the user has entered a specific population density, it means that the numbers chosen by class specification are not high enough. Since risk analysis works on worst case scenarios, and a higher population increases the risk of fatalities, the spreadsheet will choose the higher of the population densities calculated in the previous two steps.

Population Density P.D. = 0.23 persons/ha

The population density and the area affected have been calculated. It is now possible to estimate the consequences of a pipeline rupture. A mortality rate of 50% is included because a 50% fatality rate is considered catastrophic.

22. Consequences = P.D. x Area x Mortality Rate
= 0.23 people/ha x 8786 m^2/10,000 m^2/ha x 0.5 fatalities/event
= 0.10 fatalities/event

23. Probability (From the Event Tree shown on Figure 2, Section 4.2)
= F(hazard) x (Pipe Length) x P(wind) x P(ignition) x P(exposure)
= (2.0E-03 events/km-yr) x (25 km) x (0.06) x (0.12) x (0.11)
= 4.0×10^{-5} events/yr

24. Finally, **R I S K = CONSEQUENCES x PROBABILITY**
= (Step 12 x Step 13)
= $0.10 \times (4.0 \times 10^{-5})$

R I S K = 4.0×10^{-6}

Table 4 on the next page shows some comparison risks for common activities and natural phenomena. It can be seen that this particular pipeline is 'safer' than many things that people are exposed to often.

This spreadsheet calculates one risk score for an entire pipeline segment. These scores can be used for comparison with other pipelines, and with other situations. This program is intended for general comparison usage, and not to be taken without question.

TABLE 4
RISKS ASSOCIATED WITH
COMMON ACTIVITIES AND NATURAL PHENOMENA*

ACTIVITY OR PHENOMENA	RISK (fatality per exposed person per year)
Smoking (20 cigarettes/day)	5.0×10^{-3}
Mountaineering	2.0×10^{-3}
Hang-gliding	2.0×10^{-3}
All Accidents	5.0×10^{-4}
Motor Vehicle Accidents	2.5×10^{-4}
All Industrial Accidents	1.7×10^{-4}
Falls	7.2×10^{-5}
Drowning	5.0×10^{-5}
Fires	3.1×10^{-5}
Air Travel	7.0×10^{-6}
Railway Travel	2.0×10^{-6}
Lightning	8.0×10^{-7}
Meteorites	6.0×10^{-11}

* From F.G. Bercha and Associates Ltd, 1983, 1989.

Simple criteria for the acceptability of risk to the external population have been suggested and although there will never be total agreement about these, there is an emerging consensus as follows (Reference 7):

RISK OF DEATH PER YEAR TO INDIVIDUAL

$> 1 \times 10^{-4}$	Unacceptable. Action to reduce risk mandatory.
$< 1 \times 10^{-6}$	Insignificant. No action justifiable.
$10^{-6} < \text{Risk} < 10^{-4}$	Action to reduce risk may be warranted, but should be justified on a cost-benefit basis.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The purpose of this project was to develop a general method to calculate a value for the risk of an NGL pipeline. This required research into the definitions and procedures of risk analysis.

From this research, a simplified method of risk analysis for NGL pipelines, called RES (Risk Estimation Spreadsheet), was developed and incorporated into Excel 3.0 for ease of calculation. It is a combination of methods and a simplification of theories. It is a method that is best used for general comparison cases only.

Recommendations:

1. Companies are beginning to submit risk analyses witht their applications. Staff of the Pipeline Branch should be made aware of the methods and cautions involved with risk assessments.

2. Further investigation into the procedures of risk analysis is recommended. It seems to still be in its developing stage in the industry, and may become a very important part of any project.

3. The ERCB program GasCon2 could be pursued for its usage on sour gas pipelines. It is a comprehensive program that could be altered to accommodate NGL pipelines as well.

4. The Risk Estimation Spreadsheet could be used for analysis on pipelines regulated by the NEB. This could involve:
    a) trend analysis of risks
    b) comparison among different companies
    c) sensitivity analysis on parameters.

APPENDIX A

RISK ANALYSIS SOFTWARE

Risk Analysis, Vol. 11, No. 3, 1991

Software Review/Listings[1]

Risk Analysis Software and Databases: Review of Riskware '90 Conference and Exhibition

Ronald J. Marnicio,[2,6] P. J. (Bert) Hakkinen,[3] Steven D. Lutkenhoff,[4] Richard C. Hertzberg,[5] and Paul D. Moskowitz[1]

INTRODUCTION

The Ohio Chapter of the Society for Risk Analysis (SRA) hosted a one-day conference and exhibition of computer software and databases with application to the practice of risk assessment and risk management. The event, called "Riskware '90", took place on December 7, 1990 in Columbus, Ohio. The conference was co-sponsored by the U.S. Environmental Protection Agency's (EPA) Office of Research and Development, with support from Ebasco Environmental and The Procter and Gamble Company. Riskware '90 featured a morning session of invited speakers and an afternoon program of live software and database demonstrations and product displays. The group luncheon provided additional opportunities for discussion and exchange.

The objective of the conference was to bring together developers and users of computer-based risk analysis tools for a mutual educational exchange. This objective was accomplished through a combination of prepared presentations and informal discussions. Interactions throughout the day revolved around evaluations of the capabilities of the products being demonstrated relative to the particular needs of those charged with risk assessment or management duties. The event enabled the risk analysts to see the range and types of currently available products that could support them in their work, and provided the product developers the opportunity to hear first-hand feedback on the strengths and weaknesses of their products.

Diversity may best describe the conference. It is generally accepted that risk analysis encompasses a broad range of activities in many different contexts. This variety was clearly in evidence at Riskware '90. There was great diversity of backgrounds, purpose, and need among those who attended the conference and among those who developed the software and databases. More dramatic was the diversity in the style and application of the risk analysis software and databases themselves. Following is a brief summary and review of these aspects of Riskware '90.

OVERVIEW AND OBSERVATIONS

The Attendees

Approximately 120 people were in attendance at Riskware '90, including both National and Chapter members of the SRA and a significant number of non-member risk analysts from Ohio and the surrounding region. The attendees represented federal and state agencies, industry, consulting firms, and academia. Individuals from 10 states were present.

The Speakers

Two invited presentations were given during the morning session of the conference: (1) Joseph Fiksel,

[1] Edited by Paul D. Moskowitz, Brookhaven National Laboratory, Biomedical and Environmental Assessment Group, Upton, New York 11973.

[2] Ebasco Environmental, 5000 Bradenton Avenue, Suite 200, Dublin, Ohio 43017.

[3] The Procter and Gamble Company, Paper Technology Division, Miami Valley Laboratories, P.O. Box 398707, Cincinnati, Ohio 45239.

[4] U.S. Environmental Protection Agency, Office of Senior Official for Research and Development, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268.

[5] U.S. Environmental Protection Agency, Environmental Criteria and Assessment Office, 26 West Martin Luther King Drive, Cincinnati, Ohio 45258.

[6] To whom all correspondence should be addressed.

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Program Manager for Integrated Product Management with Cimflex Teknowledge, on the topic "Computer-Aided Risk Analysis in the '90s"; and (2) Philip Wexler, Technical Information Specialist for the Toxicology Information Program at the National Library of Medicine, on the topic "Information Technology in the '90s in Support of Risk Analysis."

Joseph Fiksel's presentation reviewed a broad range of "expert system" or "artificial intelligence system" concepts and capabilities with current, and possible future, application to risk analysis. Three primary trends in computer-aided risk analysis and management were highlighted. First, computers are presently enabling risk assessments to be integrated to a much greater extent. The added capability afforded by computers now allows assessments involving mixtures of chemical compounds, competing risk factors, multimedia exposures, and physical/chemical interactions to be explicitly considered and studied. Secondly, the large capacity of existing and evolving computer systems, relative to those of only a few years ago, enables physical or biological systems of much greater complexity or scale to be analyzed. Of particular note are systems that can only be modeled mathematically or cannot be simply or practically observed in a real-time physical sense. Examples of such areas are global ecology, pharmacokinetics, nonuniform dispersion of chemicals, and genetically engineered organisms. The third noted trend in computer-aided risk analysis and management related more directly to applications made possible by technological advancements and novel computer system designs and configurations. These included the development and use of distributed databases, hypermedia applications, and more advanced knowledge-based systems. Dr. Fiksel discussed the concepts of data and knowledge, accentuating their differences, and outlining computer systems for processing each. "Knowledge engineering," in both qualitative and quantitative forms, was highlighted as an area of computer-aided risk analysis that will grow dramatically in the next decade. This growth will occur as computers enable the linking and integration of models, data, and acquired knowledge. Enhancing computational capacity and capability, including interfaces that facilitate the transfer and representation of human knowledge, will accelerate this development.

Philip Wexler's presentation focused primarily on the status and future plans for "TOXNET," the toxicology data network maintained by the National Library of Medicine. The principal individual components of TOXNET and the developments planned for the next few years were each briefly identified and described. In addition, linkages between TOXNET and certain other related databases, like MEDLARS, were reviewed. Details of certain components of TOXNET most closely related to computer risk analysis were then presented. These components included the Hazardous Substances Data Bank (HSDB), the Toxic Chemical Release Inventory (TRI) Series, and the Integrated Risk Information System (IRIS). Wexler revealed that three primary additions to TOXNET were currently "on the drawing board," specifically the inclusion of the Agency for Toxic Substances and Disease Registry's Toxicological Profiles (referred to as TOXPROF), the Genetic Toxicology Files (GENETOX), and the TRI Fact Sheets (TRIFACTS). In addition to the material contents of TOXNET, Wexler's presentation addressed aspects of TOXNET's structural design and system architecture. The various ways to access TOXNET and make use of its many searching and print features also were outlined. Wexler concluded his presentation with a review of other principal risk-related databases in the United States and worldwide.

The Software and Database Developers

The afternoon session of Riskware '90 was devoted entirely to the demonstration and hands-on exploration of the represented risk-related software and databases. Approximately 40 different software packages or databases were demonstrated by their developers or representatives. In addition, descriptive materials or demonstration disks for an additional 20 relevant products were available for review and distribution. A "trial area" with free access to personal computers was established to enable attendees to try out any demonstration disks they had been given.

Twenty-three software developers or distributors participated in Riskware '90. These groups and individuals exemplified the broad diversity that was characteristic of the conference, in terms of their approach to computer analysis, their style of presentation, and their niche in the overall field of risk analysis. They included federal agencies, universities, consulting and contract research firms, large corporations, small companies, and a "one-man" operation. The exhibitors came from 12 different states and the District of Columbia, with greatest representation from California and the greater Washington, D.C. area.

The Software and Databases Exhibited

The software and databases exhibited were generally of four types: (1) general purpose programs and

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models; (2) specific purpose programs and models; (3) frameworks for decision-making; and (4) databases. In terms of fields or topics of application, the products were quite diverse. The software and databases represented at Riskware '90 included products that (in roughly decreasing order of prevalence):

- perform hazard assessment modeling of accidental and normal effluent or emission releases from industrial sites and estimate their resulting impacts;
- analyze data from cancer bioassays to help perform cancer risk assessments;
- perform fate and transport modeling of chemicals released into the air, soil, groundwater, and surface water;
- assess the risks of the manufacture, storage, and transport of chemicals;
- analyze data from health studies with noncancer endpoints;
- design and perform event tree and fault tree analyses;
- access health effects data on mixtures of chemicals;
- access the key U.S. EPA risk assessment estimates and the physical and chemical properties of particular chemicals;
- simulate the uptake, distribution, metabolism, and excretion of chemicals in animals and humans through physiologically based pharmacokinetic modeling;
- support chemical process safety management decisions through technical system and human reliability analyses;
- perform probabilistic risk or safety assessments;
- model the dynamics of wildlife and ecological populations;
- analyze accident scenarios for purposes of emergency planning and response;
- identify disease clusters;
- perform quantitative risk assessments for various chemicals and sites;
- assist in the compliance with regulatory requirements;
- track the principal United States, Canadian, and state regulations pertaining to hazardous chemicals; and
- provide a self-paced introductory educational program on the basics of toxicology and the sources of uncertainty associated with the risks posed by chemicals.

A few products demonstrated at Riskware '90 were entire frameworks for modeling with extensive built-in features and capabilities for exploring and testing the particular algebraic models developed. As such, these products offered the maximum flexibility with regard to possible application in the field of risk analysis.

The Appendix contains a compilation of the information of practical interest to most risk analysts for the products represented at Riskware '90. For each piece of software or database, the Appendix lists: the product's name; the relevant contact person's name and telephone number; the product developer or distributor's corporate name and address; the computer system required to use the product; the product's cost at the time of the conference (subject to change); and a brief description of the product and its uses. A review of the information presented in the Appendix reveals a few aspects of general interest.

Nearly three fourths of the risk-related computer products were developed for use on IBM-compatible systems. Roughly 20% of the products exhibited were available for Macintosh systems. A few products were specifically designed for use with VAX or Sun work stations, and one product was available only through remote access with a suitable telephone link-up and terminal. IBM-compatible machine products, on the whole, required systems with the capacity and capability of at least an AT-equivalent/286 processor. Requirements of a PS/1 or PS/2 system also were noted. In most cases, unencumbered work on most systems required a hard disk with at least 20 MB of memory, the addition of up to 2 MB of RAM, and a math coprocessor. Macintosh products, on the whole, generally required an SE, SE30, or II machine. In general, most products would not appear to be able to be used effectively without a color graphics monitor. A laser or postscript printer is indicated to be the standard hardcopy output device for most products, while a few products required a pen plotter for outputting results.

The majority of risk-related computer products required little in the way of supporting software and tended to run independently from the operating system or other resident programming languages. These were often compiled, executable versions of programs written in C, BASIC, FORTRAN, or a special-purpose language. A few products piggy-backed onto other software packages. Foremost among these were products that enhance the performance of spreadsheet or database packages such as Lotus 1-2-3, Excel or dBase.

The costs of the products represented were as varied as the products themselves. The standard corporate rate purchase price for the products exhibited ranged from $120 to $17,500. Site licenses for certain specialty products were generally much more, with examples as high as $130,000. Some products were available through

monthly leases or annual subscriptions. Discounts to the prime corporate rate were indicated to be available to universities, other academic institutions, and government agencies. Multiple-copy or high-volume purchasers also may receive discounted prices.

DISCUSSION/CONCLUSIONS

The Riskware '90 conference met a need that has been growing over the last several years. The use of computers in risk analysis is increasing dramatically. This increase is reflected in the size and complexity of the problems and situations that can be analyzed, in the degree to which the various components and levels of the analysis can be integrated, in the extent that data and modeling input selection can be facilitated and guided in an informed manner, and in the extent that the knowledge and logic of the risk analyst can be translated into the algorithms of the software. Great numbers of risk-related computer products appear and disappear each year. Indeed, it was found that a number of the software packages reviewed in the last couple of years in *Risk Analysis* are not now being offered due either to a changing market which eliminated the need for their capability or which required significant modification and redesign of the package. Others evolve and persist. The ever-growing number of risk analysts, many of whom are new to the field, have been looking for a practical way to find out about the state of the art in computer-based techniques and capabilities for analyzing and communicating risks. Conversely, new challenges in risk assessment and risk management call for new capabilities from those who develop the software and databases. These developers recognize this and wish to respond. A forum to facilitate this interaction in the specific context of risk analysis has been needed for some time. Riskware '90 was the first attempt at filling this need.

Many observations at Riskware '90 may be considered as trends of things to come in the upcoming decade. Riskware '90 highlighted the need for software and database developers to view these new opportunities with a sense of responsibility and challenge. Certainly, the increasing use of computers to eliminate the tedious or routine aspects of risk analysis (e.g., number crunching, information retrieval) is one example. This application may have been one of the principal inroads of computers into the field. While this capability can free the risk analyst for more stimulating or interesting elements of the work, it was often noted in the conference presentations and discussions that the accuracy, credibility, and appropriateness of any "canned" computer models or data must be clearly established and maintained over time. Given the current explosion of "user-friendly" products (replete with buttons, menus, and windows), an untrained user can generally select risk data or models for use outside of their range of application without constraint or appropriate guidance or caveats as to their proper use. This challenge must be met for computers to continue to play an increasing role in risk analysis. The advances and incalculable potential of knowledge-based systems may well provide the answer to this concern. A second general observation is that care must be taken to retain a suitable focus and emphasis on the development of the scientific foundations of the software and databases. Commensurate advancements in graphical displays and color outputs have been critical to the acceptance of computer-aided risk analysis by a broader audience. However, it should be recognized that results are more likely to be accepted without question when they are beautifully formatted and graphically portrayed. The Garbage In/Garbage Out adage will continue to apply to computer-aided risk analysis in the 1990s.

Notwithstanding these challenges to the continued development of software and databases for risk analysis, Riskware '90 painted a bright picture for the years ahead. Many more groups are participating in product development, and a growing number of risk analysts are becoming educated in the responsible use of these products. Spillovers of risk analysis tools from one application to another will occur with increasing frequency. Computer hardware capabilities, in terms of CPU size and speed and input/output device sophistication, will drive the development of new products and capabilities. Greater complexity and integration will be possible. More on-line documentation and instructional or explanative features will be provided that will help the risk analyst to use the products wisely. The development of knowledge-based systems will eventually help the user pick the most appropriate models and input data for the given circumstances through a question-and-answer exchange. Developments will certainly be fast, and will be of more practical and scientific value to the field if there is regular, meaningful interaction between the users and the developers of the products.

APPENDIX

Compendium of Information on the Software and Databases Exhibited at Riskware '90

Program: @RISK

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Source: William T. Barton, (607) 277-8000, Palisade Corporation, 31 Decker Road, Newfield, New York 14867

System: @RISK for 1-2-3 Release 2.X or Symphony Release 2.0 or higher: IBM PC, 512 KB RAM, graphics adapter. @RISK for PC Excel Version 2.1c or higher with Windows 3.0: IBM AT, 2 MB RAM, hard drive, graphics adapter. @RISK for Mac Excel Version 2.2 or higher: Mac Plus with 1 MB RAM, hard drive

Cost: @RISK for 1-2-3/Symphony — $395; site licenses; volume and academic discounts available. @RISK for PC Excel — $395; site licenses; volume and academic discounts available. @RISK for Mac Excel — $395; site licenses; volume and academic discounts available

Description: @RISK is a 1-2-3/Symphony/Excel add-in for risk analysis using Monte Carlo simulation. Probability distributions are added to cells using 30 new probability distribution built-in functions. A Lotus or Excel style menu lets users choose Monte Carlo or Latin Hypercube sampling, select output ranges, and start simulating. Results are displayed graphically and statistics are calculated and displayed

Program: ACSL (Advanced Continuous Simulation Language)

Source: Keri Michaud, (508) 369-5115, Mitchell and Gauthier Associates, 73 Junction Square Drive, Concord, Massachusetts 01742

System: IBM PC or compatibles, 640 KB RAM, hard drive, math coprocessor; graphics monitor. Macintosh 2 MB RAM, Fortran

Cost: PC/ACSL — $2,300; MAC/ACSL — $3,950; PC-386/ACSL — $3,950. Discounts available

Description: ACSL is used to simulate dynamic systems. In this case, ACSL is used to simulate the uptake, distribution, metabolism, and excretion of chemicals in animals or humans. PHYSIM is a demonstration disk with a compiled physiologically based pharmacokinetics (PB-PK) model. PB-PK models are used to understand the behavior of chemicals in the body and determine target tissue dosimetry for risk assessment purposes

Program: ATMS (Air Toxics Modeling System)

Source: John Takacs, (617) 451-1201, Ebasco Environmental, 211 Congress Street, Boston, Massachusetts 02110-2410

System: IBM PC 386, 640 KB RAM, hard drive, math coprocessor mouse; laser printer, color plotter; EGA or VGA color monitor; MS-DOS 3.3

Cost: $15,000–$50,000 depending on complexity of site graphics and the need to incorporate new chemicals, release scenarios, and models

Description: Ebasco's air contaminant release assessment software provides a user-friendly, interactive system that leads either experienced or novice users through liquid or gas release characterization, air model selection, model execution, and graphic display of results. The system is customized to a facility to include site-specific chemicals, release scenarios, and digitized USGS maps for color display. The system currently uses five EPA-recommended transport and diffusion models which analyze any type of release. These public-domain models are incorporated into the system in modular form and are easily updated or replaced as new modeling techniques become available. Because these models are EPA accepted, the need to validate the performance of a proprietary model is eliminated

Program: BIOASSAY

Source: Frank W. Carlborg, (708) 584-1690, P.O. Box 1284, Saint Charles, Illinois 60174

System: IBM PC, 250 KB RAM; MS DOS, BASIC

Cost: $150

Description: The program provides statistical support for a large class of experiments in which the outcome is measured as a proportion: Survival analysis, effective dose analysis, relative potency analysis, cancer bioassay analysis, and cancer risk assessment. Also included are the basic statistical analyses for proportions

Program: CAFTA+

Source: Jim Koren, (415) 960-5946, Science Applications International Corporation, 5150 El Camino Real, Suite C-31, Los Altos, California 94022

System: IBM PC, 640 KB RAM; DOS 2.0 or higher

Cost: Single copy — $7,900; limited site license — $19,500

Description: CAFTA+ workstation includes a full-screen fault tree editor, multilevel reliability database, versatile plotting package, powerful cut set generation routine, and unique cut set results editor. CAFTA+ is a tool for managing construction, plotting, and evaluation of fault tree models. CAFTA+ is designed to assist the analyst in extracting information concerning the strengths and weaknesses of the modeled system

Program: CAHAZOP, Version 1.3 (Computer Aided HAZard and OPerability Study)

Source: Frank S. Dombek, (619) 451-2131, NUS Cor-

poration, 16835 West Bernardo Drive, Suite 202, San Diego, California 92127

System: IBM PC, 640 KB RAM, hard drive (desirable but not essential); CGA monitor; laser printer (HP II or III), dot matrix printer; dBASE IV Version 1.1 (Ashton Tate), LCD viewgraph projection unit recommended; PC-DOS/MS-DOS

Cost: $2000, discounts available. Note the software package is *included* with the course materials for the NUS course titled "Practical Hazard Identification Methods". Demo and User Manual available on request

Description: CAHAZOP is a software tool that aids in the conduct of Hazard and Operability (HAZOP) studies. The software provides the structure for a self-documenting database manager that greatly accelerates HAZOP data recording; helps team members to perform the HAZOP study in a systematic manner; provides a series of pre-programmed reports and user-controlled options to review the HAZOP information; ensures conformity of HAZOP study formats; and as an additional benefit, permits a complete "electronic audit trail" documenting the conduct of the study. Use of the CAHAZOP software in conjunction with an LCD overhead projector display unit provides measurable benefits. The projected HAZOP worksheets serve as a focus for the HAZOP team's hazard identification process and the visual presentation of the data-taking process allows immediate review of the study information for completeness and correctness greatly reducing future review requirements and improving quality assurance of the study.

Program: CARA (Computer Aided Reliability Analysis)

Source: Jim O. Byrne, (714) 447-9400, Technica Inc., Software Products Division, 1400 N. Harbor Blvd., Suite 440, Fullerton, California 92635

System: IBM PC / XT / AT / PS/2, 640 KB RAM, 5 MB hard drive, math coprocessor; EGA or VGA monitor, laser or dot-matrix printers or plotter (e.g., HP-series, Calcomp); DOS 3.3 or higher

Cost: Single-copy purchase price — $9995, includes one upgrade and technical support. Single-module pricing, multiple-copy discounts, and leasing available upon request. Special pricing for universities

Description: User-friendly PC toolkit composed of four menu-driven modules to allow safety and reliability engineers to perform quick and efficient analyses. Modules include: fault tree construction and analysis (CAFTAN); failure modes, effects, and criticality analysis (FMECA); cause consequence analysis (CCA); and failure rate data analysis (ANEX)

Program: CAST (Cluster Analysis in Space and Time)

Source: Geoffrey M. Jacquez, (516) 751-4350, Applied Biomathematics, 100 North Country Road, Setauket, New York 11733

System: IBM PC, 640 KB RAM, hard drive, math coprocessor (optional); EGA/VGA monitor; DOS 2.0 or higher

Cost: Single-user license — $395; site license — $795

Description: CAST is a program for the display and statistical description of disease clusters. Man's activities change the environment, and some of these changes cause cancer and other afflictions. The problem is to determine whether an excess of disease —a cluster — exists. CAST blends state-of-the-art statistics and 3D graphics to fully describe a suspected cluster

Program: CHEM-RISK

Source: B.O.Y. Lydell, (619) 451-2131, NUS Corporation, 16835 West Bernardo Drive, Suite 202, San Diego, California 92127

System: IBM PC, 640 KB RAM, hard drive, math coprocessor; CGA monitor, pen plotter supporting HPGL (7475A up), or laser printer (simulating HPGL plotter, or with external software package that turns HPGL files into laser plots); PC-DOS/MS-DOS

Cost: $2500; discounts available. Note: The software package is *included* with material for the NUS one-week course in "Hazards Evaluation Methods." Demo floppy and users manual available on request, at no cost

Description: CHEM-RISK is a general-purpose event tree/fault tree code for applications to CPI risk assessment projects. The fault tree module builds on the NUSSAR-II algorithms. Includes modules for database development, event tree/fault tree construction, uncertainty and sensitivity analysis

Program: CHEMS-PLUS, Version 2.0

Source: George Melhem, (617) 864-5770 x5408, Arthur D. Little, Inc., Acorn Park, Cambridge, Massachusetts 02140-2390

System: IBM PC, hard drive

Cost: $545, or $100 to upgrade from Version 1.0; quantity discounts are available

Description: CHEMS-PLUS v. 2.0 is a simplified package of hazard assessment models for emergency planning. CHEMS-PLUS offers models for release rates, vapor dispersion, fire, and explosion hazards. Version 2.0 offers new models such as: improved flame jet, simplified heavy

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gas dispersion, and others. Version 2.0 also offers better menu control and lets the user create "macros" for common scenarios.

Program: Crystal Ball
Source: Eric Wainwright, (303) 298-0020, Market Engineering Corporation, 1738 Wynkoop Street, Suite 200, Denver, Colorado 80202
System: Any Macintosh with at least 1 MB RAM; any one of the following: Microsoft Excel, Microsoft Works, Full Impact, or WingZ
Cost: Standard Price — $395; university price — $149; call for site licensing
Description: With this Macintosh Monte Carlo simulation program, users assign probability distributions to input cells (on imported spreadsheet models) and get frequency distributions for dependent formulas. Graphics provide intuitive understanding of situations. Crystal Ball includes 11 standard distributions; custom distributions; descriptive statistics; sensitivity analysis; high performance; and documentation. Version 2.0 includes correlated variables; Latin Hypercube Sampling; and "trend charting"

Program: DEMOS
Source: Brian Arnold, (415) 325-0342, Carnegie Mellon University, Schenley Park, Pittsburgh, Pennsylvania 15213
System: Any Macintosh computer with at least 1.5 MB RAM; System Software Version 6.0.x or newer
Cost: Beta version with manuals — $20
Description: DEMOS, a *de*cision *mo*deling *s*ystem, is a general engineering modeling tool for constructing, analyzing, reviewing, and communicating probabilistic models to support decision-making in policy, economics, and risk analysis. Applications include automobile safety, power plant chemical emissions, and controlling effects of acid rain.

Program: EPIcode
Source: Steven Homann, (415) 490-6379, HOMANN Associates, Inc., 39831 San Moreno Court, Fremont, California 94539
System: IBM PC / XT / AT, 512 KB of RAM; MS-DOS 2.1 or higher
Cost: $495
Description: EPIcode is a completely menu-driven MS-DOS software package for health and safety professionals. EPIcode is used in emergency planning and response for fast risk assessment and estimation of the concentrations resulting from the atmospheric release of toxic substances. The 600-substance library contains AIHA TLV-TWA and STEL, ERPGs, and NIOSH IDLH guidelines. The library can be expanded by the user

Program: ETA-II
Source: Jim Koren, (415) 960-5946, Science Applications International Corporation, 5150 El Camino Real, Suite C-31, Los Altos, California 94022
System: IBM PC, 640 KB RAM; HPGL plotter or Postscript printer, CGA monitor; DOS 2.0 or higher
Cost: Limited site license — $4900
Description: ETA-II is an interactive program designed for building and modifying event tree models in a graphic mode. The reliability analyst can use ETA-II to build event trees from scratch, refine and improve them, quantify event sequences, and produce report-quality plots of the completed trees

Program: FaultrEASE
Source: George Melhem, (617) 864-5770 x5408, Arthur D. Little, Inc., Acorn Park, Cambridge, Massachusetts 02140-2390
System: Macintosh Plus, SE, SE/30, and all II models with 2 MB of RAM; Apple Laserwriter, Apple Imagewriter, or Postscript printers
Cost: Single-user license fee of $375; quantity discounts are available; includes a comprehensive manual
Description: FaultrEASE is an interactive graphics editor for fault trees. FaultrEASE was developed for use in the Macintosh environment and, therefore, uses standard Macintosh conventions for menus, mouse clicks, and windows. Fault trees are constructed and edited by selecting symbols with a mouse and entering information into a dialog box. FaultrEASE uses the supplied information to automatically lay out the fault tree and its associated text. Logical mathematical calculations also are performed. FaultrEASE produces report-quality graphics that are identical both on screen and in printouts. In addition to these capabilities, FaultrEASE is equipped with a variety of features that allow a high degree of flexibility in layout

Program: FRANTAGE
Source: Tatyana Ginzburg, (516) 751-4350, Applied Biomathematics, 100 North Country Road, Setauket, New York 11733
System: IBM PC / AT / PS/2, 640 KB RAM, an Intel 80x87 math coprocessor chip, hard drive; CGA, EGA, VGA, or Hercules monitor; IBM compatible printer; DOS 2.0 or higher
Cost: Single-user license — $950; site license —

$1200. University discount: single-user license — $350; site license — $650. Government: $100 handling and maintenance fee

Description: FRANTAGE calculates risk time trends in system unavailability versus age. It allows users to model both linear and nonlinear aging effects with threshold times. Periodic and dynamically changed surveillance test intervals can be modeled to evaluate maintenance programs for their effectiveness in controlling aging impacts on system risk

Program: FRANTIC ABC
Source: Tatyana Ginzburg, (516) 751-4350, Applied Biomathematics, 100 North Country Road, Setauket, New York 11733
System: IBM PC / AT / PS/2, 640 KB RAM, an Intel 80x87 math coprocessor chip, 1 hard drive; CGA, EGA, VGA, or Hercules monitor; IBM compatible printer; DOS 2.0 or higher
Cost: Single-user license — $950; site license—$1,200. University discount: single-user license—$350; site license — $650. Government: $100 handling and maintenance fee
Description: FRANTIC ABC is used for time-dependent probabilistic risk assessment and reliability analysis of complex systems. It allows users to evaluate risk contributors associated with periodic or irregular testing and generates test placements which satisfy user-specified technical specification restrictions

Program: GLOBAL86
Source: Cynthia Van Landingham, (318) 255-4800, K. S. Crump Division, Clement International Corporation, 1201 Gaines Street, Ruston, Louisiana 71270
System: IBM PC / XT / AT / PS/2 / PS/1, 640 KB RAM; math coprocessor optional; DOS 3+ or OS/2 1.3
Cost: $1195
Description: A program that fits the multistage model to quantal dose–response data with an option that implements a selection process for the number of stages in the linearized multistage analyses. Also features a bootstrap method for assessing goodness-of-fit

Program: HAZOPtimizer
Source: George Melhem, (617) 864-5770 x5408, Arthur D. Little, Inc., Acorn Park, Cambridge, Massachusetts 02140-2390
System: IBM PC, hard drive, math coprocessor (optional), extended memory management
Cost: Single-user license fee of $375; with quantity discounts available
Description: HAZOPtimizer software can be used to record and document the results of Hazard and Operability studies (HAZOPs), Failure Modes and Effects Analyses (FMEAs), Preliminary Hazard Analyses (PHAs), "What-If" Analyses or any other type of hazard identification or risk assessment technique that uses a columnar format. It is a menu-driven program. Users have full control over the format of files and can define new formats. Users may create a different format for each analysis or select a previously defined format. Each time a new format is defined, it is saved as a template file for future use. HAZOPtimizer comes with several predefined formats for HAZOPs and other hazard identification techniques

Program: HAZSEC (HAZOP Recording Software)
Source: Jim O. Byrne, (714) 447-9400, Technica Inc., Software Products Division, 1400 N. Harbor Blvd., Suite 440, Fullerton, California 92635
System: IBM PC / XT / AT / PS/2, 640 KB RAM, hard drive; EGA or VGA monitor; laser or dot-matrix printer; DOS 3.1 or higher
Cost: Corporate licenses available upon request
Description: HAZSEC represents the state of the art in software technology for recording HAZOP studies. Programmed in "C," HAZSEC features Easy-to-use Pull Down Menus, WYSIWYG Logsheet Data Entry, Unlimited Logsheet Size, Integrated Recommendation Database. Allows user to customize: Logsheet Design, Guideword List, Report Format

Program: ICRMS (International Chemical Regulatory Monitoring System)
Source: Kenneth B. Clansky, (301) 907-7771, Ariel Research Corporation, 7910 Woodmont Avenue, Suite 902, Bethesda, Maryland 20814
System: IBM PC, hard drive. Data files are available in ASCII code on 3-1/2" and 5-1/4" diskettes, and in both ASCII and EBCDIC code on 9-track magnetic tape. ICRMS data files (without Ariel software) may be used in conjunction with a wide range of database management software on most micro, mini, and mainframe computers
Cost: The ICRMS is licensed on an annual subscription basis. North American corporate annual license fees range from $8500–$18,500
Description: The ICRMS is a database and software tool that enables chemical manufacturers and users to keep track of key federal, state, and Canadian regulations that pertain to the manufacture,

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transportation, use, and release of chemicals. A European module is currently in development

Program: IMES (Integrated Model Evaluation System)
Source: Richard Walentowicz, (202) 475-8922, U.S. Environmental Protection Agency, Office of Research and Development (RD-689), 401 M Street, SW Washington, D.C. 20460
System: IBM-AT, 1.2 MB floppy drive, hard drive; EGA color monitor
Cost: Not yet determined
Description: The U.S. EPA Office of Health and Environmental Assessment develops methodologies for conducting exposure and risk assessments. A part of these efforts has been to develop and implement protocols: (1) to aid in the selection of an exposure assessment model and (2) to assess the validation and uncertainties associated with models used for toxic chemical exposure assessments in surface water, groundwater, and air. These protocols have been applied to selected models and applications of these models, and a software package—IMES—has been developed to provide potential users with a quick and intuitive tool to access the available information. IMES is composed of the following modules: (1) Selection — query systems for assisting in the selection of an exposure assessment model (currently for nonpoint source, surface water, and groundwater models; an air module is to be added); (2) Validation — a database containing validation and other general information on over 50 exposure assessment models and applications in air, surface water, and groundwater (additional information on these models and others is being added); and (3) Uncertainty — a database containing the results of prediction uncertainty for several surface water model simulations applied to exposure assessments of several chemicals. The goal is to have the system incorporate information on uncertainty and validity in the selection process using AI techniques.

Program: IRIS (Integrated Risk Information System)
Source: Jacqueline Patterson, (513) 569-7574, U.S. Environmental Protection Agency, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268
System: IBM PC, 5-1/4" high capacity floppy drive, or terminal with modem
Cost: The user must pay for diskettes or communication service access to the system. *Diskettes:* National Technical Information Service (NTIS) $130. Updated quarterly. *On-line:* (a) TOXNET — National Library of Medicine. Updated monthly. (b) Electronic mail through BT-Tymnet. Updated monthly
Description: IRIS is an on-line database of the U.S. Environmental Protection Agency that provides risk assessment and EPA regulatory information on over 400 chemical substances. The risk information is reviewed and agreed upon by agency-wide work groups and represents the most up-to-date agency risk values

Program: MIDAS (Meteorological Information and Dispersion Assessment System)
Source: Mark J. Abrams, (202) 659-1122, PLG. Inc., 1615 M Street, NW, Washington, D.C. 20036
System: IBM 386 PC, 2 MB RAM, hard drive, math coprocessor, mouse; VGA monitor; MS-DOS 3.3 or higher. UNIX workstation version. VAX running under VMS Version 5.0 or higher
Cost: $20,000–$50,000; lease arrangements/volume discounts available
Description: MIDAS is a software package that collects meteorological and effluent data and calculates the environmental impact of gaseous releases from nuclear or industrial facilities on the local area. The system can quickly estimate the real-time plume location and concentration for use by plant personnel and emergency response organizations

Program: MIXTOX
Source: Richard C. Herzberg, (513) 569-7582, U.S. Environmental Protection Agency, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268
System: PC-AT, hard drive; dBaseIII
Cost: Free, available on request
Description: Stand-alone dBASE III-compatible database and access program containing summaries of all published articles on toxicologic interactions. Primarily reflects studies on two chemical interactions. Currently contains 2983 records reflecting 1631 chemical pairs, 864 distinct chemicals, 455 research articles. Package includes 2 high-capacity diskettes, User's Guide, and upgrade information sheet

Program: MULTIWEIB
Source: Cynthia Van Landingham, (318) 255-4800, K. S. Crump Division, Clement International Corporation, 1201 Gaines Street, Ruston, Louisiana 71270
System: IBM PC / XT / AT / PS/2 / PS/1, 640 KB RAM (DOS 3+), 2.5 MB RAM (OS/2 1.3), math coprocessor (optional), floppy or hard drive; DOS 3+0 or higher or OS/2 1.3

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Cost: $1195
Description: A program that fits time-to-tumor dose–response data to a model that is multistage in dose and Weibull in time. Estimates the probability $P(d,t)$ of a response by a particular time t, selected by the user

Program: NUPRA
Source: P.J. Fulford, (301) 258-6000, NUS Corporation, 910 Clopper Road, P.O. Box 6032, Gaithersburg, Maryland 20877-0962
System: IBM PC, 640 KB RAM, hard drive, 1 high-density diskette drive, math coprocessor; CGA monitor; pen plotter supporting HPGL (7475A up) or laser printer (simulating HPGL plotter, or with external software package that turns HPGL files into laser plots); DOS 3.0 or higher
Cost: $17,000; discounts available. *No* demo floppy, but demonstrations can be arranged by contacting NUS. Detailed users manual and applications manual are available
Description: NUPRA is a software system for Level 1 and 2 PRA/PSA. It is an interactive menu-driven system comprising six major analysis modules and a seventh module of utility functions

Program: NUSSAR-II
Source: B.O.Y. Lydell, (619) 451-2131, NUS Corporation, 16835 West Bernardo Drive, Suite 202, San Diego, California 92127
System: IBM PC, 640 KB RAM, hard drive, math coprocessor; CGA monitor; pen plotter supporting HPGL (7475A up) or laser printer (simulating HPGL plotter, or with external software package that turns HPGL files into laser plots)
Cost: $3500; discounts available. Demo-floppy and users manual available on request at no cost
Description: NUSSAR-II is a general purpose code for fault tree analysis; fault tree construction, fault tree solution (MCS-generation), and fault tree quantification (including time-dependent calculations). Fault trees are constructed using on-screen graphics input format. The current capacity and limitations are: (1) 500 gates, 500 logic gates; (2) 150 internal transfers, 45 external transfers; and (3) through fault tree linking/merging, fault trees with up to 3000 gates, 3000 logic gates can be solved

Program: PC-MIDAS
Source: Mark J. Abrams, (202) 659-1122, PLG. Inc., 1615 M Street, NW, Washington, D.C. 20036
System: IBM PC 286, 640 KB RAM, hard drive; VGA monitor; MS-DOS 3.1 or higher
Cost: $15,000–$25,000; lease arrangements/volume discounts available
Description: PC-MIDAS is a stand-alone device that collects meteorological and effluent data and automatically displays the potential plume location based on the latest 5-minute average of the data. The plume is displayed on site-specific color maps updated every 5 minutes

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Program: PHAST (Process Hazards Analysis Software Tools)
Source: Jim O. Byrne, (714) 447-9400, Technica Inc., Software Products Division, 1400 N. Harbor Blvd., Suite 440, Fullerton, California 92635
System: IBM PC / XT / AT / PS/2, 640 KB RAM, hard drive, math coprocessor (optional); EGA or VGA monitor; laser or dot-matrix printer or plotters (e.g., HP-series, Calcomp); DOS 3.3 or higher
Cost: Single-copy license — $17,500 includes one upgrade and technical support. Multiple-copy discounts and leasing available upon request. Special pricing for universities
Description: PHAST is capable of predicting the toxic and flammable effects of releases of hazardous materials using state-of-the-art models for: dense clouds, jet sprays, buoyant plumes, spreading and evaporating pools, BLEVEs, pool fires, fireballs, and vapor cloud explosions. AIChE's DIPPR physical property database. Supports high-quality graphics to laser printers and HPGL files for import into word processors

Program: PLAN
Source: David T. Hulett, (213) 395-9866, PLAN Systems International, L.P., 11693 San Vincente Blvd., Suite 350, Los Angeles, California 90049
System: IBM PC / XT, graphics card; PLAN for Lotus, Lotus 1-2-3 Version 2.0 or higher; PLAN for Project Management, works with most project management software including Primavera, Promis, Viewpoint
Cost: PLAN for Lotus with up to 100 distributions — $999 to $1499; PLAN for Lotus with up to 300 distributions—$2999 to $4499; PLAN for Project Management — $5000 to $10,000 (available with Primavera 2/91; other versions soon thereafter)
Description: PLAN for Lotus — PLAN is a decision tool which offers an alternative to the Monte Carlo Technique for distribution analysis by utilizing true mathematical manipulation of probability functions (convolutions). PLAN effectively extends the utility of conventional spreadsheet analysis by allowing the user to specify ranges

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on input assumptions and deriving the likelihood distributions for the "what-if" outcomes. PLAN permits the separation of analysis on the one hand from decision- or policy-making on the other using the "S-curve." PLAN uses your spreadsheet, and is "file-compatible" with Lotus.

PLAN for Project Management — PLAN permits the calculation of the probability to complete the project on time including an analysis of when "near-critical path" activities extend the "expected completion date" beyond that of traditional CPM analysis. Problem activities and nodes (or joinings) are identified and ranked. PLAN uses your network and activity descriptions

Program: QCRR (Quantification of Chemical Release Risk)
Source: Mark J. Abrams, (202) 659-1122, PLG. Inc., 1615 M. Street, NW, Washington, D.C. 20036
System: IBM 286 PC, 640 KB RAM, hard drive; MS-DOS 3.1 or higher
Cost: $5000–$10,000; volume discounts available
Description: QCRR computes risk in terms of probability of exceeding toxic chemical concentrations from accidental releases. QCRR incorporates meteorological data from on-site/off-site measuring stations. Output is presented as risk contours on a color map of the site.

Program: RAMAS/age
Source: Scott Ferson, (516) 751-4350, Applied Biomathematics, 100 North Country Road, Setauket, New York 11733
System: IBM PC / XT / AT / PS/2, 384 KB RAM, math coprocessor (optional); DOS 2.0 or higher
Cost: Single-user license—$195; site license—$400
Description: RAMAS/age is used to produce and analyze models of the population dynamics of a biological species. It allows users to define simple or age-structured models that include density dependence and variance due to environmental fluctuations or demographic stochasticity. It computes the expected growth or decline and estimates the risks of extinction and the chance of population explosion.

Program: RAMAS/space
Source: H. Resit Akcakaya, (516) 751-4350, Applied Biomathematics, 100 North Country Road, Setauket, New York 11733
System: IBM PC / XT / AT / PS/2; CGA, MCGA, EGA, VGA, Hercules, AT&T 400 or 3270 PC graphics or 80-column monochrome monitor; DOS 2.0 or higher
Cost: Single-user license — $195; site license — $400
Description: RAMAS/space is used for building spatially structured population models for species that exist in multiple populations, for example, threatened species in fragmented habitats. It can be used to estimate risk of extinction of species, design of nature reserves, and to evaluate wildlife management practices such as translocation of organisms among populations or reintroductions

Program: RAMAS/stage
Source: Scott Ferson, (516) 751-4350, Applied Biomathematics, 100 North Country Road, Setauket, New York 11733
System: IBM PC / XT / AT / PS/2, 512 KB RAM, math coprocessor (optional); graphics monitor recommended; DOS 2.0 or higher
Cost: Single-user license — $250; upgrade from RAMAS/age — $200; site license — $500
Description: RAMAS/stage is a flexible matrix-based system for modeling the population dynamics of biological species with complex life histories. It can switch between numerical and graphical models. Eigen analysis is used to estimate the asymptotic behavior of the population, and simulation is used to estimate the short-term risks of population growth, decline, or extinction

Program: RBDA
Source: Jim Koren, (415) 960-5946, Science Applications International Corporation, 5150 El Camino Real, Suite C-31, Los Altos, California 94022
System: IBM PC, 640 KB RAM, and hard drive; Postscript printer or HP pen plotter; DOS 2.0 or higher
Cost: Single copy — $7900; limited site license — $16,900
Description: RBDA workstation is a tool for building, modifying, and evaluating reliability block diagram (RBD) models. It provides a flexible, interactive environment for development and analysis of small or large multisystem models. It can obtain cut sets from RBDs and perform sensitivity studies, all on stand-alone PC. RBDA workstation includes: block diagram/database editor, cut set generator, and cut set results editor

Program: RecoveryPAC
Source: Ken Bauman, (203) 431-8720, Computer Security Consultants, Inc., 590 Danbury Road, P.O. Box 875, Ridgefield, Connecticut 06877
System: IBM PC / XT / AT / PS/2, 640 KB RAM,

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extended memory is supported; hard disk drive; MS-DOS or PC-DOS Version 3.1 or higher
Cost: Single copy license price — $15,000
Description: Large data center and total organization contingency planning

Program: RecoveryPAC II
Source: Ken Bauman, (203) 431-8720, Computer Security Consultants, Inc., 590 Danbury Road, P.O. Box 875, Ridgefield, Connecticut 06877
System: IBM PC / XT / AT / PS/2, 640 KB RAM, extended memory is supported, hard drive; MS-DOS or PC-DOS Version 3.1 or higher
Cost: Single copy license price — $3000
Description: Small to mid-range data center and business department resumption planning

Program: Risk*Assistant
Source: Russell Kinerson, (202) 475-8915, U.S. Environmental Protection Agency, Office of Research and Development (RD-689), 401 M Street, SW, Washington, D.C. 20460
System: IBM PC/XT, 512 KB, high density 5-1/4" drive, hard drive; EGA monitor
Cost: Not yet determined
Description: Risk*Assistant is a microcomputer-based software system being developed by the U.S. EPA in conjunction with Hampshire Research for the purpose of conducting risk assessments. It is designed to be applied to specific sites and chemicals. The user inputs the chemical concentration data at the point of exposure and the system retrieves the relevant toxicological data, provides defaults for the various exposure parameters, and produces a report summarizing the results and important assumptions. The system uses a pull-down menu interface with on-screen help covering both operational and scientific information. The currently available version is a Beta-type (fully operational but being distributed primarily for review purposes) and a final release is scheduled for early 1991.

Program: RISK*RANK
Source: Robert W. Johnson, (614) 424-4762, Battelle, Process Risk Management Services, 505 King Avenue, Columbus, Ohio 43201
System: IBM PC/AT, 1 MB RAM; Lotus 1-2-3 Release 3, DOS 3.0 or higher
Cost: Single-user license for $900, survey form, and User's Guide
Description: RISK*RANK offers users an easy, reliable, and inexpensive method for assessing process-chemical combination relative to risk of toxic inhalation casualty, analyzing their chemical usage in various locations and determining the relative risk of a toxic chemical release. RISK*RANK surveys the user for input for each process-chemical combination concerning 10 key areas

Program: RISKMAN
Source: John P. Kindinger, (714) 833-2020, PLG, Inc., 4590 MacArthur Boulevard, Suite 400, Newport Beach, California 92660-2027
System: IBM 386 PC, 3 MB RAM, hard drive, math coprocessor; EGA or VGA monitor; MS-DOS 3.3 or higher
Cost: $45,000
Description: RISKMAN is a completely integrated menu- and window-driven software system for performing quantitative risk analysis. This software has been principally used to perform large and comprehensive probabilistic safety assessments for nuclear power plants. The software, however, is not specific to nuclear plants; it can be used to analyze the frequency of event sequences for scenarios in any industrial system or plant.

Program: RiskPAC
Source: Ken Bauman, (203) 431-8720, Computer Security Consultants, Inc., 590 Danbury Road, P.O. Box 875, Ridgefield, Connecticut 06877
System: IBM PC / XT / AT / PS/2, 640 KB RAM, and hard drive; MS-DOS or PC-DOS Version 3.1 or higher
Cost: Single copy license price — $5000 to $9500
Description: Interactive, automated risk assessment product which uses built-in expert knowledge base and questionnaire-style user interface

Program: RiskPAC System Manager
Source: Ken Bauman, (203) 431-8720, Computer Security Consultants, Inc., 590 Danbury Road, P.O. Box 875, Ridgefield, Connecticut 06877
System: IBM PC / XT / AT / PS/2, 640 KB RAM, hard drive; MS-DOS or PC-DOS Version 3.1 or higher
Cost: Single copy license price — $10,000
Description: Optional module to CSCI's RiskPAC. Modifies RiskPAC questionnaires or creates customized questionnaires. Provides control over question development, scoring, and modification

Program: RISKPRO
Source: Linda Peters, (301) 953-2700, General Sciences Corporation, 6100 Chevy Chase Drive, Suite 200, Laurel, Maryland 20707
System: IBM XT, AT or PS/2 386, 640 KB RAM, hard

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drive 1 floppy drive, 8087, 80287, or 80387 math coprocessor (optional); DOS 2.2 or higher

Cost: Core System $425, plus individual modules ranging from $295 to $1495 each. Complete system $5795. Discounts for universities and government

Description: RISKPRO is a user-friendly integrated software system designed to predict the exposure and risk of toxic chemicals released to the environment. The system contains a variety of sophisticated EPA-approved fate and transport models for chemical releases to air, soil, groundwater, and surface water. Also includes environmental datasets, chemical property estimation programs, graphical displays of model output, and mapping capabilities

Program: RMQS

Source: Jim Koren, (415) 960-5946, Science Applications International Corporation, 5150 El Camino Real, Suite C-31, Los Altos, California 94022

System: IBM PC / PS/2, 384 KB RAM, hard drive; DOS 2.0 or higher

Cost: Limited site license — $30,000

Description: RMQS is a manager for an integrated risk model for large engineered systems (nuclear power plants, chemical plants, and space systems). It links results from various models into one database, enabling sensitivity, what-ifs, and plant modification studies to be performed rapidly. Effects of changes across all accident scenarios can be evaluated

Program: SAFETI

Source: Jim O. Byrne, (714) 447-9400, Technica Inc., Software Products Division, 1400 N. Harbor Blvd., Suite 440, Fullerton, California 92635

System: PC Version: IBM PC 386, 3 MB extended memory, hard drive, math coprocessor (required); EGA or VGA monitor; laser printer or plotters (e.g., HP-series); DOS Version 3.3 or higher. Mainframe version also available

Cost: Single-copy license—$130,000, includes training and maintenance contract. Corporate leasing licenses available upon request

Description: SAFETI is an integrated set of computer programs designed to automate the risk assessment of chemical and petrochemical facilities involving the manufacture, storage, and transport of toxic and flammable materials. Calculates the consequences of possible accidental releases and their impact based on event frequency to produce measures of risk, such as Risk Contour Plots and f-N curves.

Program: SARATRAX

Source: Clyde Lichtenwalner, 1-800-458-1564, IIT Research Institute, 2719 Pulaski Highway, Edgewood, Maryland 21040

System: IBM PC / XT / AT / PS/2, 640 KB RAM, hard drive; DOS 2.0 or higher

Cost: Basic System $900. Various additional modules available, including support service. Discounts offered

Description: SARATRAX is an inventory tracking and emergency-spill reporting system designed to assist the user in complying with the requirements of SARA Title III, the Emergency Planning and Community Right-to-Know Act. SARATRAX tracks inventories and usage of hazardous chemicals, pure and in mixtures. SARATRAX leads the user through the regulatory requirements associated with spill reporting, including determining if an RQ was spilled, providing the emergency phone numbers to call, and providing draft follow-up letters to the regulatory agencies. SARATRAX modules allow the customer to build a custom compliance package. In addition to the basic system, the following modules are available: (1) Chemical Data Base — contains EPA's List of Lists and all pertinent data; (2) Form R Assistance — aggregates hazardous material usage for Section 313 reporting; (3) Generic Inventory Interface — allows automated inventory update using other sources of data; (4) Multi-Facility/Client Interface — allows multiple facility reporting using one SARATRAX system; (5) HP Laser Jet or Adobe Postscript (and compatibles) Printer Interface — allows direct printing of Tier and Form R forms from your laser printer; and (6) User Support — adds a year of user support to the standard 3 months provided free with the basic system

Program: SHERI

Source: Robert W. Johnson or Dr. T. Takahashi, (614) 424-4762, Battelle, Process Risk Management Services, 505 King Avenue, Columbus, Ohio 43201

System: IBM PC, 640 KB RAM; DOS 2.0 or higher

Cost: Not yet determined. Final version available first quarter 1991

Description: System for Human Error and Reliability Investigation (SHERI) is a tool for supporting human reliability analysis (HRA). SHERI brings the THERP (Technique for Human Error Rate Prediction) method from a very large handbook, usable only by those well acquainted with the methodology, to your PC, enabling consistent analysis for even the nonexpert user

Program: SOCRATES
Source: Dave Wagner, (614) 424-4762, Battelle, Process Risk Management Services, 505 King Avenue, Columbus, Ohio 43201
System: IBM AT, 640 KB RAM, math coprocessor (80387), and hard drive; DOS 2.0 or higher
Cost: Single-user license—$15,000; multiple-user and site licenses available
Description: Evaluates risk impacts of system test and maintenance strategies. Calculates changes in risk as a function of user-defined changes in surveillance test schedules and maintenance outage times. Allows both multiple and nonperiodic tests for individual equipment items. Sensitivity studies can be performed on any input parameter.

Program: Spectrum / PC-F&E
Source: Robert W. Johnson or Steve Rudy, (614) 424-4762, Battelle, Process Risk Management Services, 505 King Avenue, Columbus, Ohio 43201
System: IBM PC / XT / AT, 320 KB RAM, hard drive or high density floppy; DOS 2.0 or higher
Cost: Spectrum software package — $12,000; Fire and Explosion module only (PC-F&E) — $7500; site licenses and monthly leases available. Two-day training session available
Description: Spectrum is a tool for use in managing chemical process safety. It integrates information from detailed surveys into a *unified risk profile*, which includes severe accident risks associated with fire, explosions, toxic releases, environmental damage, and business interruptions. Spectrum includes a computerized version of Dow Chemical's Fire/Explosion Index methodology. Physical/chemical data on over 250 chemicals are also included

Program: SuperChems
Source: George Melhem, (617) 864-5770 x5408, Arthur D. Little, Inc., Acorn Park, Cambridge, Massachusetts 02140-2390
System: IBM compatible PC 286/ 386, math coprocessor, hard drive; CGA, VGA or EGA
Cost: $15,400. Substantial discounts are available when multiple copies are purchased
Description: SuperChems is a detailed hazard modeling package designed to meet the hazard analysis needs of most sophisticated users, while offering the ease-of-use that will appeal to newcomers to the field. The package includes detailed models for release rate, pool behavior, jet behavior, vapor dispersion, and different types of fires and explosions. It handles both pure compounds and mixtures. The package runs both linked and stand-alone models. Predefined macros are provided for commonly analyzed cases, and user-specified "project" macros can be created, allowing a sequence of models to be run for multiple sets of input data. The package includes a 1000 compound database incorporating DIPPR data. Users may add their own materials

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Program: TEC/ET (Free Jet and Plume Dispersion Model)
Source: Jim O. Byrne, (714) 447-9400, Technica Inc., Software Products Division, 1400 N. Harbor Blvd., Suite 440, Fullerton, California 92635
System: IBM PC / XT / AT / PS/2, 640 KB RAM, hard drive, math coprocessor (optional); EGA or VGA monitor, laser or dot-matrix printer or plotter (e.g., HP-series, Calcomp); DOS 3.3 or higher
Cost: Single-copy purchase price — $7500, includes annual upgrade and technical support. Multiple-copy discounts and leasing available upon request. Special pricing for universities
Description: TEC/ET is a specialized jet momentum model suitable for predicting both the continuous discharge and the dispersion of free jets and plumes from vents, stacks, flares, relief valves, rupture disks, and piping/vessel failures. TEC/ET provides both graphical and tabular results for plume concentration vs. downwind distance. Contains 40 chemicals from AIChE's DIPPR physical property database

Program: THRESH
Source: Cynthia Van Landingham, (318) 255-4800, K. S. Crump Division, Clement International Corporation, 1201 Gaines Street, Ruston, Louisiana 71270
System: IBM PC / XT / AT / PS/2 / PS/1, 640 KB RAM (DOS 3+)/2.5 MB RAM (OS/2 1.3), math coprocessor (optional), floppy or hard drive; DOS 3.0 or higher or OS/2 1.3
Cost: $1195
Description: A program that uses the benchmark dose method for establishing a reference dose for a chemical. THRESH fits the multistage threshold model to animal data and can be used for noncancer endpoints

Program: THRESHW
Source: Cynthia Van Landingham, (318) 255-4800, K. S. Crump Division, Clement International Corporation, 1201 Gaines Street, Ruston, Louisiana 71270
System: IBM PC / XT / AT / PS/2 / PS/1, 640 KB RAM (DOS 3+)/2.5 MB RAM (OS/2 1.3),

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math coprocessor (optional), hard drive; DOS 3.0 or higher or OS/2 1.3

Cost: $1195

Description: A program that uses the benchmark dose method for establishing a reference dose for a chemical. THRESHW fits the Weibull threshold model to animal data and can be used for noncancer endpoints

Program: TOX_RISK Version 3

Source: Cynthia Van Landingham, (318) 255-4800, K. S. Crump Division, Clement International Corporation, 1201 Gaines Street, Ruston, Louisiana 71270

System: IBM PC / XT / AT / PS/2 / PS/1, 640 KB RAM (DOS 3+)/2.5 MB RAM (OS/2 1.3), math coprocessor (optional), high-density floppy or hard drive; DOS 3.0 or higher or OS/2 1.3

Cost: $5000

Description: A menu-driven software package that provides the user with a convenient environment in which to perform standard types of health risk assessments. The procedures implemented by TOX—RISK are most frequently used in the estimation of carcinogenic risk. Bundled with Version 3 is a companion program TOX—DATA and a database of animal data for over 300 chemicals. TOX—RISK creates a time-to-tumor data set for TOX—RISK from a user selected chemical, study, and combination of cancer endpoints contained in the database

Program: Toxicology and Public Health: Understanding Chemical Exposure

Source: Holly Ouderkirk, (607) 255-2091, Cornell University, Media Service Distribution Center, Cornell University, 8 Research Park, Ithaca, New York 14850

System: IBM PC / XT, hard drive; EGA monitor

Cost: No charge for a demonstration disk; Not-For-Profit single copy — $120; Not-For-Profit site license — $250; Corporate Rate single copy — $175; Corporate Rate for unlimited use at up to 10 separate sites — $600; Corporate Rate for unlimited worldwide use — $6000

Description: Self-paced instructional program providing users the equivalent of introductory or continuing education course on the basics of toxicology and the sources of uncertainty about the risks posed by chemicals. All fundamental concepts are covered, using over 200 chemicals as examples. No previous computer experience is necessary to use the program

Program: UNCERT

Source: Jim Koren, (415) 960-5946, Science Applications International Corporation, 5150 El Camino Real, Suite C-31, Los Altos, California 94022

System: IBM PC, 640 KB RAM; DOS 2.0 or higher

Cost: Limited site license — $5900

Description: UNCERT determines uncertainty of system failure probabilities or accident sequence frequencies based on input uncertainties. UNCERT reads CAFTA's cut set and database files, performs Monte Carlo random sampling, and displays results graphically on the screen as the run progresses. UNCERT evaluates top event probability equations developed from top event cut sets using either minimum cut upper bound or inclusion/exclusion form

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Program: VAPACT

Source: Robert W. Johnson or Dave Hesse, (614) 424-4762, Battelle, Process Risk Management Services, 505 King Avenue, Columbus, Ohio 43201

System: IBM PC 386/486, 4 MB RAM, hard drive; DOS 3.0 or higher

Cost: $15,000 single-user license with chemical database; site licenses and monthly leases are available

Description: The VAPACT (Vapor Impact) model is a computer code for analysis of fire/explosion/toxic release consequences following loss of containment of a volatile liquid or gas. Beginning with the source term model, VAPACT generates the inputs for a subsequent dispersion and consequence impact analysis. Outputs include risk contours, f-N curves, point risk estimates, concentration and dose profiles, and source term calculation results. VAPACT can handle multicomponent releases, time-varying release rates, and mitigation features

Program: WHAZAN (World Bank Hazard Analysis Software)

Source: Jim O. Byrne, (714) 447-9400, Technica Inc., Software Products Division, 1400 N. Harbor Blvd., Suite 440, Fullerton, California 92635

System: IBM PC / XT / AT / PS/2, 512 KB RAM, hard drive, and math coprocessor (optional); CGA/EGA/VGA monitor; dot-matrix printers; DOS 3.0 or higher

Cost: Single-copy license — $1750, includes installation support. Multiple-copy discounts and leasing available upon request

Description: WHAZAN is a PC-based hazards screening tool based on the World Bank publication: "Techniques for Assessing Industrial Hazards: A Manual." Includes over a dozen basic models which predict the behavior of hazardous materials spilled onto the ground or released into the air.

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The Riskware '91 Conference and Exhibition will be held in Baltimore in December 1991 in conjunction with the Annual Meeting of the Society for Risk Analysis. NOTE: The views in this paper are those of the authors and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency.

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APPENDIX B

ERCB GASCON2 INFORMATION

- Input and Output
- Limitations

GASCON2 INPUT DATA REQUIRED

Release information:

1. H2S concentration of concern (ie 100 ppm)
2. Diameter of rupture
3. Angle of release (0 or 180)
4. Height above ground (0 m)
5. Event time (time for 99% of gas to be released) (30 min)

Gas information:

6. Volume fraction of H2S, mole fraction
7. Volume fraction of CH4, mole fraction
8. Lower heating value, MJ/m3
9. Specific heat, J/kg deg.C
10. Molecular mass, kg/mole

Meteorological information:

11. Specific heat flux, W/m3
12. Reference wind speed, m/s
13. Reference height of wind speed, m
14. Surface ambient temperature, deg. C
15. Surface atmospheric pressure, KPa
16. Surface roughness, m
17. Mixed layer height (unstable atmosphere), m (minimum = 50 m)
18. Site latitude, degrees

Pipe parameters information:

19. Pipe length, m
20. Inside diameter, mm
21. Operating Pressure, kPa
22. Compressibility factor
23. Moody friction factor
24. Pipe volume multiplier (a user's constant)
25. Ratio of rupture area/pipe area
26. Setback distance from pipe, km

Population information:

27. Reference concentration (which to calculate at), ppm
28. Population density (could be an array), persons/ha

GASCON2 OUTPUT:

Output is user-controllable. This is a list of likely desired pipeline rupture scenario output.

1. H2S concentrations:
   - at time vs. distance given exposure time
     (along plume centerline) (grid)
   - calculated hazard zones
     distance given time and concentration
     ie, 1000 ppm, 3 minutes (value)

2. Risk data at plume centreline
   - at distances (grid)
   - intensity, intermittency, prob(100 ppm) (table)

3. Probability of lethality
   - XY plot of probabilities of fatality (grid)
   - maximum potential fatalities
     (from population density in risk input)
     (sensitive to population grid size) (value)

GASCON2 LIMITATIONS:

The ERCB report lists these conditions as the program's limitations:

1. Limited Pipeline Release Scenarios. Only End Pipe Ruptures are evaluated.

2. Upwind and Downwind Horizontal Jets. The model cannot evaluate horizontal cross wind releases.

3. Combustion Module Gas Chemistry. The model assumes the sour gas is comprised of methane (CH_4), carbon dioxide (CO_2), and H_2S only. Other gases are accounted for in the heat of combustion factor.

4. No Condensation Effects. Condensate aerosol clouds are not considered.

5. Steady State Atmospheric Conditions. Assumes constant atmospheric conditions throughout event.

6. Travel times less than a few hours. Light winds cause disorganized, recirculating wind flows, which limits the model's accuracy beyond 10 km. A wind speed of 1 m/s and a distance of 10 km corresponds to a travel time of 3 hours.

7. Averaging periods ranging from a few minutes to a few hours. Estimates three-minute to one-hour average H_2S concentrations, and up to three-hour SO_2 concentrations.

8. Flat and Homogeneous terrain conditions. Large hills and valleys create steering or deflecting effects that are not accounted for. Moderately rough terrain can be modelled by using an appropriate surface roughness value.

9. H_2S Lethality. Consequence estimates are based only on H_2S inhalation.

10. Population Outdoors and Stationary.

11. Average Adult Population. The parameters used to describe human response to H_2S are representative of average adults, and may not be applicable to sensitive populations (ie, elderly, children).

APPENDIX C

REFERENCES

AND

LISTING OF OTHER READINGS ON RISK ANALYSIS

REFERENCES

1. Bercha, F.G. and Associates Ltd, "Zone 2 Risk Assessment of Fort Saskatchewan to Swan Hills Transportation System for Miscible Flood Liquids", for Federated Pipelines, September 1983.

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13. Ex, Barbara, "Software for Assessing Chemical Hazardous Risks", Pollution Engineering, January 1992.

14. Fearnehough, G.D., "Control of Risk in Gas Transmission Pipelines", Institution of Chemical Engineers Symposium: "Assessment and Control of Major Hazards", April 1985.

15. Gas Processors Suppliers Association, "SI Engineering Data Book".

16. Lawrence, W.E. and Johnson, E.E., "Design for Limiting Explosion Hazard", Chemical Engineering, January 1974.

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18. Morrow, T.B.,"When an LPG Line Breaks, How Does the Product Release/Disperse?", Pipeline and Gas Journal, June 1982.

19. Reed Stenhouse Ltd, "Risk Assessment Review of Servitude Exposures - Place St. Eustache", for TransNorthern Pipeline, July 1990.

20. Younger, A.H., "Natural Gas Processing Principals and Technology", University of Calgary, 1987.

ADDITIONAL READINGS ON RISK ANALYSIS

BINDER
TAB #

41 "Risk Analysis Requirements and Guidelines"
Canadian Standards Association, Draft Standard Q634, March 1989

42 "GASCON2 User Guide"
ERCB and Concord Environmental, October 1990.

43 "Minimum Dilution in the Atmosphere and the Application to Uncontrolled Gas Releases"
Air and Waste Management Association; Presented at the 84th Annual Meeting, Vancouver, June 1991.

44 "Software for Assessing Hazardous Chemcial Risks"
Barbara Ex, Pollution Engineering, January 1, 1992.

45 "Risks and Their Assessment - The Application of Risk Assessment Techniques to Major Hazard Pipelines"
R.A. Cox, Pipelines and the Environment, Chapter 6, pp 62-69, 1984.

46 "Risk Analysis - A Methodology for Assessing the Safety of Pipelines"
B. Morgan; Presented to the Pipeline Industries Guild February 16 1989.

47 "Risk Assessment Methods for Vapour-Cloud Explosions"
L. Cave, Progress in Energy Combustion Science, Vol. 6, pp 167-176, 1980.

48 "Risk Assessment of Sour Gas Facilities"
W.B. Andrews and L.D. Atwell; Presented at the PNWIS-APCA Annual Meeting, 1979.

49 "Estimation of Impacts from a Rupture of the Adsett Pipeline"
Western Research for Westcoast Energy Inc, October 1990.

50 "The Combined Use of Engineering and Reliability Analyses in Risk Assessment of Mechanical and Structural Systems"
P.M. Besuner, A.S. Tetelman, G.R. Egan, C.A. Rau; Presented at "Risk Benefit Methodology and Application" Conference, California, September 1975.

51 "Risk Analysis: the Process and Its Application"
A.A. Moghissi, Engineering Applications of Risk Analysis, pp 1-6, Dec. 1987.

APPENDIX D

USER'S GUIDE

(INCLUDING DATA TABLES)

RISK ESTIMATION SPREADSHEET USER'S GUIDE

THIS SPREADSHEET OPERATES ON EXCEL 3.0.
IT WILL NOT OPERATE ON EXCEL 2.1d

This user's guide is a summary of the report on the development of RES. It does not contain any theory or explanation of the calculation steps; that information is included in the report. The report should be read thoroughly before relying solely on this guide.

There are 4 sections that require input for the use of RES. The cells are shaded in the spreadsheet. The cells that are not shaded in the same column as the required input values contain values that are generally constant, but can be changed as needed.

The spreadsheet can be found on the computers under F:\PERMANENT\RES.

All of the calculation and text cells in the spreadsheet are locked under a password. This is to prevent accidental erasure of calculations. The input column is not locked. The password is 'risky', in case any changes to the body of the spreadsheet are desired.

It is only necessary to print out the first page of each analysis. The other two pages are for calculations only.

RISK ESTIMATION SPREADSHEET DATA INPUT CATEGORIES:

The first input cell is for **PIPELINE COMPANY.** This is self-explanatory.

1) PIPELINE DATA

Required Input:

Inner Diameter	-	from company data
Pipeline Segment Length	-	companies should report ESD spacing
Rupture Fraction	-	area of rupture relative to pipe area

Optional Input:

Friction Factor	-	generally for pipelines, F = 0.014

2) GAS IN PIPELINE DATA

Required Input:

Pressure	-	from company data
Molecular Weight	-	from TABLE 1 included
Lower/Upper Flammability Limits	-	from TABLE 1 included

Optional Inputs:

Type of Gas in Pipeline	-	assume propane, unless exact composition of NGL is known.
Gas Temperature	-	generally, gas flows at 10°C (283 F)
Specific Heat Ratio	-	NGL specific heat ratio = 1.26
Gas Compressibility (Z)	-	Since NGL flows as a liquid, Z = 1

3) POPULATION DATA

Required Input:

Class Type, or	-	from company data
Actual Dwelling Units/ha	-	if this value is available from the company, or use TABLE 2 for an estimation

Optional Input:

Location	-	for user's information
Direction to Population	-	for user's information
Mortality Rate	-	a 50% mortality rate is considered catastrophic

4) METEOROLOGICAL DATA

Required Input:

θ (Horiz. Dispersion)	-	from TABLE 3 included
ϕ (Vertical Dispersion)	-	from TABLE 3 included
Wind Speed	-	obtain a most probable wind speed from TABLE 4 included, or use 4 m/s

Optional Input:

Wind Direction	-	for user's information

5) PROBABILITY DATA

Required Input:

Frequency of Hazard	-	from NEB's incident database
Probability of Wind Conditions	-	from TABLE 4 included

Optional Input:

Probability of Ignition	-	USA data indicates 12% of NGL leaks ignite
Probability of Exposure	-	a general factor to account for human behaviour

DATA TABLES FOR RISK CALCULATIONS

TABLE 1
PHYSICAL CONSTANTS OF COMPONENTS OF NATURAL GAS
From: GPA Publication 2145 SI-80

Component	Methane	Ethane	Propane	Iso-Butane	n-Butane
Molecular Weight	16.04	30.07	44.09	58.12	58.12
Flammability Limits					
Lower, ppm	500	290	210	180	180
Upper, ppm	1500	1300	950	840	840

TABLE 2
TYPICAL POPULATION DENSITIES (Alberta Data)
From: ERCB (1990)

High Urban	30 dwelling units/hectare
Low Urban	5
High Rural	1.67
Low Rural	0.17
Agricultural	0.03

TABLE 3
THETA AND PHI VALUES (degrees)
Horizontal and Vertical Dispersion Factors
From: Davies et al (1991)

	Zo = 15 cm (very rough)		Zo = 5 cm (rough - ie 1 m high crop)		Zo = 1 cm (ie, crop stubble		Zo = 0.2 cm (smooth - ie, snow)		Average	
	Theta	Phi	Theta	Phi	Theta	Phi	Theta	Phi	Theta	Phi
Stability Class										
A (daytime,unstable)	25	13	21	11	15	8	11	6	18	10
B (daytime, unstable)	20	11	17	9	12	6	8	5	14	8
C (daytime, unstable)	15	9	13	7	9	5	6	4	11	6
D (neutral)	10	6	8	5	6	4	4	3	7	5
E (night, stable)	6	4	5	3	3	2	2	2	4	3
F (night, stable)	<3.8	<2.4	<3.2	<2.0	<2.2	<1.4	<1.6	<1.0	3	2

TABLE 4 - EXAMPLE WIND DATA FOR MAJOR CENTRES IN CANADA
From: Environment Canada, Canadian Climate Normals Vol. 5

	PERCENTAGE FREQUENCY (%)								
Direction	N	NE	E	SE	S	SW	W	NW	Calm
Yellowknife, NWT	8.0	8.1	12.5	6.4	6.3	1.9	3.9	8.8	4.0
Calgary, AB	9.9	2.7	3.3	5.9	9.9	5.2	11.0	6.8	8.3
Whitehorse, YT	6.0	0.5	0.9	17.3	15.6	2.6	2.5	7.7	12.1
Lac La Biche, AB	4.2	3.1	3.8	8.6	9.0	4.2	8.8	9.1	16.6
Edmonton, AB	5.0	1.8	3.4	9.1	12.0	4.0	9.2	7.3	7.7
Lethbridge, AB	5.5	3.5	3.4	3.4	4.9	11.4	18.6	4.8	4.1
Medicine Hat, AB	6.1	3.9	5.9	1.6	3.7	21.6	9.2	6.5	7.3
Peace River, AB	11.3	6.2	3.0	1.6	5.2	10.3	10.7	3.8	7.3
Regina, SK	4.7	1.9	5.8	14.4	4.4	3.5	10.0	9.8	2.6
Saskatoon, SK	5.6	5.7	4.8	7.3	7.9	6.6	7.1	7.3	3.7
Toronto, Int'l Airport	11.0	2.6	4.6	4.2	6.1	7.3	11.0	9.0	5.0
Winnipeg, MN	8.6	4.3	2.9	4.9	14.5	3.6	7.8	10.0	2.8
Quebec, Que.	5.7	7.0	5.5	0.6	1.4	11.8	10.8	4.0	6.9
Windsor, Ont.	5.5	6.0	4.4	3.1	7.3	10.4	8.4	4.1	5.4
Dawson Creek, BC	4.1	6.5	4.1	8.9	6.4	18.7	20.0	6.4	24.9
Sarnia Polysar, Ont.	4.4	7.0	4.8	16.6	17.1	16.2	13.5	19.5	0.9

Note: Frequencies may not add up to 100% because there are 8 other directions not included here.

	MEAN WIND SPEED (m/s)							
Direction	N	NE	E	SE	S	SW	W	NW
Yellowknife, NWT	4.4	4.1	4.4	4.6	4.5	3.6	4.1	5.1
Calgary, AB	5.5	3.7	3.6	4.2	3.7	3.2	7.2	4.7
Whitehorse, YT	3.3	1.8	2.1	5.3	4.7	3.1	2.3	3.3
Lac La Biche, AB	2.7	2.4	2.9	3.9	2.6	3.1	4.3	3.3
Edmonton, AB	4.2	3.2	3.6	4.6	3.4	2.4	3.7	5.2
Lethbridge, AB	4.9	3.9	3.2	3.7	4.1	5.8	8.2	4.5
Medicine Hat, AB	4.4	3.4	3.7	2.9	4.7	4.9	5.8	5.1
Peace River, AB	4.1	3.7	2.9	2.7	2.9	3.6	4.6	3.3
Regina, SK	5.2	4.6	5.3	6.5	4.6	4.9	5.6	6.6
Saskatoon, SK	5.3	4.8	4.7	5.3	4.5	4.5	4.6	6.1
Toronto, Int'l Airport	4.1	3.4	4.8	3.5	3.4	4.9	5.0	4.7
Winnipeg, Man.	5.8	4.4	4.5	5.0	6.0	4.0	4.6	6.0
Quebec, Que.	2.7	4.0	4.5	2.3	2.7	5.4	5.2	4.5
Windsor, Ont.	4.9	4.7	3.7	3.6	4.2	5.1	5.4	5.7
Dawson Creek, BC	3.1	2.5	2.6	2.9	3.8	5.5	5.1	3.6
Sarnia Polysar, Ont.	4.2	3.9	3.4	4.0	4.6	4.6	3.8	4.5

RISK CALCULATIONS FOR RUPTURES IN NGL PIPELINES

PIPELINE COMPANY	PTC	
PIPELINE DATA		
Inner Diameter (m)	0.1589 m	
Pipeline Segment Length (km)	25 km	(IN KILOMETRES)
Rupture Fraction	1.00	(Ar/Ap = 1.0 or 0.5, etc)
Friction Factor F	0.014	(Generally for pipelines, F = 0.014)
GAS IN PIPELINE DATA		
Type of Gas in Pipeline	Propane	
Pressure (KPa)	9928 KPa	
Molecular Weight	44 g/mol	
Upper Flammability Limit	910 ppm	
Lower Flammability Limit	210 ppm	
Gas Temperature To	283 K	(NGLs flow at approximately 10 deg.C)
Specific Heat Ratio ke	1.26	(Typically, ke = 1.26 for Natural Gas) (1)
POPULATION DATA		
Approximate Location	Medicine Hat, AB	
Direction to Population	West	(ie, if West, then use an East wind...)
Class Type (1, 2, 3)	1	(1= 5 d.u., 2 = 40 d.u., 3 = 60 d.u.)
Actual Dwelling Units/ha , if known	0	(0 if not known)
Mortality Rate	0.5	
METEOROLOGICAL DATA		
Wind Direction	East	
Wind Speed	4 m/s	
Theta (Horizontal Dispersion)	10	(high Theta and Phi values for rough
Phi (Vertical Dispersion)	5	surfaces and unstable atmospheres)
PROBABILITY DATA		
Frequency of Hazard =	2.0E-03 incidents/km-year	
Probability of Wind Conditions =	0.059	(from local wind probabilities)
Probability of Ignition =	0.12	(U.S. data indicates P(ignition)=0.12) (2)
Probability of Exposure =	0.11	

Probability of Event = 3.9E-05 events/year
Consequences of Event = 1.0E-01 fatalities/event

R I S K = PROBABILITY x CONSEQUENCES

This pipeline has a risk of 4.0E-06 fatalities/year
or, 1 in 249411 chance of fatality.

DATA CALCULATIONS PAGES

GAS RELEASE DATA

Pipeline Gas Constant Re =	189	J/kgK
Speed of Sound in Gas Co	260	m/s
Pipeline Cross-Sectional Area =	2.0E-02	m2
Area of Pipeline Rupture Ar =	2.0E-02	m2
Initial Mass Release Rate mo =	562	kg/s
Event Mass Release Rate Me =	109	kg/s
Event Release Rate (kg/s-->m3/s)=	0.6	m3/s

(constants calculations)

Ke+1/Ke-1 =	8.69
Time Constant	0.11
e =	3388
Total Mass (kg)	
Mt =	119657
Mass Conversion Factor:	
n =	0.126
n^2 * e =	54

AREA AFFECTED DATA

Distance to Upper Flam. Limit Xu =	41	m
Distance to Lower Flam. Limit Xl =	85	m
Distance to Explosion Epicenter XE=	63	m
Mass Within Flammability Limits =	723	kg
TNT Equvalent =	7	tons
Radius of Overpressure Circle =	12	m (from Epicenter)
Radius of Hazardous Area =	75	m

Area Affected by Overpressures and Fire Danger = 8786 m2

POPULATION DATA

Dwelling Units by Class Spec:	5	d.u.
Population Density by Class Spec:	0.23	people/ha
Population Density by User Input:	0.00	people/ha
Larger Population Density =	0.23	people/ha

Consequences = Area x Pop. Den. x Mortality Rate = 1.0E-01 people fatalities/event

(1) A.H. Younger, U of C, Natural Gas Processing Principals and Technology 1987
(2) R. A. Cox, Pipelines and the Environment

Mass Release Rate
(the 'change' at Time t=0 is 10000 so the initial release rate is included in averaging - the criteria states a change greater that 1.0 kg/s, but there is no change at time t=0 so a dummy value is included.)

Time, s	Release, kg/s	Change, kg/s
0	561.86	10000
10	238.33	323.53
20	202.97	35.36
30	173.62	29.35
40	149.25	24.37
50	129.02	20.23
60	112.22	16.80
70	98.26	13.95
80	86.67	11.59
90	77.03	9.63
100	69.03	8.01
110	62.37	6.66
120	56.83	5.54
130	52.22	4.61
140	48.38	3.84
150	45.18	3.20
160	42.51	2.67
170	40.28	2.23
180	38.41	1.87
190	36.85	1.56
200	35.54	1.31
210	34.43	1.10
220	33.50	0.93
230	32.72	0.79
240	32.05	0.67
250	31.49	0.57
260	31.00	0.48
270	30.58	0.42
280	30.22	0.36
290	29.91	0.31
300	29.64	0.27
310	29.40	0.24
320	29.18	0.21
330	28.99	0.19
340	28.82	0.17
350	28.66	0.16
360	28.51	0.15

Database Criteria		
Time, s	Release, kg/s	Change, kg/s
		>1.0

Average Release Rate = 109 kg/s